McKinsey
Global Institute

Discussion paper

Connected world

An evolution in connectivity
beyond the 5G revolution

February 2020

McKinsey Global Institute

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Discussion paper

Connected world: An evolution in connectivity beyond the 5G revolution

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In brief

Connected world: An evolution in connectivity beyond the 5G revolution

The world's digital connections are about to become broader and faster, providing a platform for every industry to boost productivity and innovation. We have identified hundreds of use cases across more than 17 commercial domains that can run on an enhanced digital backbone. This research focuses on four of them: mobility, healthcare, manufacturing, and retail.

We find that implementing the most promising use cases we identified in these four areas alone could increase global GDP by $1.2 trillion to $2 trillion by 2030, with the countries that are most connected today capturing much of the value. These four domains represent roughly one-third of global GDP, implying that there are opportunities to create trillions of dollars in additional value across other sectors. On top of this, some two billion new users are set to come online worldwide, generating another $1.5 trillion to $2 trillion in GDP impact, mostly in the developing world.

However, although most of the needed technologies are already available and the opportunities have existed for some time, progress has yet to take off in many areas. Questions about who makes the required investments, who benefits, and how to coordinate multiple players still must be solved.

— The future of the connected world is not just about the newest frontier technologies, such as high-band 5G and low-earth orbit satellite constellations. Much of it will be defined by the expansion and evolution of existing advanced connectivity technologies, like fiber, low- to mid-band 5G, Wi-Fi 6, and various other long- and short-range solutions. The new architecture of connectivity also features cloud and edge computing that can be accessed with cheaper and more efficient "thin" devices. Computing power, storage, and sensors are all growing more powerful and more affordable. As these trends converge, the connectivity ecosystem will be populated with more technologies, services, and providers than ever before.

— While consumer demand for entertainment and internet applications will continue to drive most network usage, connectivity enables new capabilities across the economy. To illustrate the range of what is possible, we highlight a number of promising use cases in four commercial domains. In **mobility,** vehicles will communicate with infrastructure, other vehicles, and networks, improving safety and traffic flow. In **healthcare,** connectivity-enabled innovations can make it possible to monitor patients remotely, use AI-powered tools for more accurate diagnoses, and automate many tasks so that caregivers can spend more time with patients. **Manufacturers** and other industrial companies can run highly precise, high-output, and largely automated operations using low-latency commercial and private 5G networks. **Retailers** can offer a more seamless and personalized in-store experience while making inventory management and warehouse operations more efficient.

— Out of the $1.2 trillion to $2 trillion potential in these four domains, 70 to 80 percent can be achieved with existing advanced connectivity technologies. With its improved speed, efficiency, latency, and coverage, frontier connectivity can produce the remainder by taking many existing use cases to the next level—and paving the way for entirely new ones that we cannot foresee today. However, most providers and industry players are not bolting out of the starting gate. In many places, investment has yet to materialize at the scale of the opportunity.

— For this to happen, several issues clouding the market will need to be solved in each of the four domains. For one, coordination across value chains is a

critical challenge. Second, the potential value is fragmented across many use cases but lacking a clear aggregator to provide scale. In addition, incentives are often misaligned. The entity doing most of the heavy lifting of investment and implementation may not be the one who stands to benefit financially. Furthermore, many use cases introduce data complexities, in terms of privacy, security, and interoperability. Finally, deployment constraints in the form of regulatory barriers, capital availability, and long investment cycles are leading both connectivity providers and industry players to put upgrades on hold in many regions. These issues existed in the previous technology cycle, and they are carrying forward with greater urgency. Tackling them can potentially unlock trillions of dollars—not just in these four domains but in others as well.

– Apart from industry use cases, up to 2 billion additional users could come online by 2030, due to a combination of network expansions, growing affordability of devices and services, and other factors. Overall, the share of the global addressable population remaining wholly offline or limited to only the most basic connectivity (that is, not yet using 3G-capable data networks or better) could shrink by half, from 40 percent today down to 20 percent. The economic and social benefits would be profound, from improved access to mobile banking and credit to new educational opportunities.

– Delivering connectivity enhancements will come at a cost. We estimate that by decade's end networks can be expanded and upgraded to cover approximately 80 percent of the global population with advanced connectivity, at a cost of some $400 billion to $500 billion. However, connectivity providers are unlikely to have sufficient incentive to offer frontier coverage in most of the world. Only a quarter of the global population is likely to gain high-band 5G coverage by 2030, with rollout costing some $700 billion to $900 billion. Given the magnitude of the investment required, connectivity providers will continue to face a tough road. Many of them are already struggling to meet shareholder demands while considering capital investments to enhance their networks.

– Despite the promise of a more inclusive connected world, disparities between countries could persist. Analyzing revenue potential, cost factors, and market dynamics, we see four country archetypes progressing along the connectivity continuum at varying speeds, as well as two countries that stand apart. **Pioneer countries** (including the United States, Japan, and South Korea) **and China** are ahead on the connectivity continuum; they are already deploying the first high-band 5G networks in select major cities. **Leader markets** such as France and Canada will be close behind. **Followers,** such as Brazil and Poland, are a few years back; their near- to medium-term focus is likely to be on fiber and mid-band 5G. **Trailing countries** such as Pakistan and Bolivia are unlikely to gain widespread advanced connectivity, let alone frontier connectivity, in the near term. **India** has modernized its mobile networks at breakneck speed, but frontier connectivity will likely be limited to its major urban centers. In addition to the gaps across these archetypes, the urban-rural connectivity gap within countries could widen. These patterns of deployment will affect how the value from domain use cases is ultimately distributed, favoring pioneer countries and China.

– A number of questions remain open. Can providers capture long-term economic value by partnering with businesses in other domains? What will the connectivity ecosystem look like in a decade's time, and what new competitors and players might enter? Will companies opt to build their own private networks rather than relying on public services? To what extent will processing migrate to the edge? Will providers continue to struggle with monetizing consumer entertainment and internet applications, or will new applications change this dynamic? How much more value potential exists in other commercial domains, and do they have their own unique barriers to adoption that need to be addressed? Lastly, the role policy makers will take in shaping the connected world of the future remains unclear. The actions governments choose to take in areas such as regulation, spectrum, infrastructure access, R&D funding, and even subsidies will have major implications for where, when, and how the world connects. We plan to explore some of these issues in future research.

Executive summary

The promise of 5G has captured the attention of business leaders, policy makers, and the media. But how much of that promise is likely to be realized anytime soon?

With the first true high-band 5G networks already live, we set out to take a realistic view of how and where connectivity could be deployed and what it can enable over the next 10 years. But 5G is not appearing in isolation. This research takes a more expansive view of connectivity to include other technologies, ranging from fiber and satellites to Wi-Fi and short-range technologies.

Despite the hype about remote surgery and *Star Trek*–style holodecks in everyone's living rooms, the future is not solely happening on the frontier. Existing connectivity technologies are expanding and evolving, with new standards that boost network performance—and they are much less capital-intensive. We have identified an enormous array of use cases that can run on this type of upgraded backbone. Companies do not have to wait for high-band 5G to implement new systems and go after the resulting productivity gains.

To illustrate what is possible, this research looks at how connectivity could be deployed in mobility, healthcare, manufacturing, and retail. The use cases we identified in these four commercial domains alone could boost global GDP by $1.2 trillion to $2 trillion by 2030. This implies that the value at stake will ultimately run trillions of dollars higher across the entire global economy.

Most of this value can be captured with advanced connectivity, using technologies that have been available for some time now. This raises a puzzling question: Why is so much potential still sitting on the table, and will new technologies alone be enough to realize it? This research looks at the issues holding back the market, with the aim of starting a broader conversation about what it will take to create momentum. It is part of an ongoing body of work that will continue exploring connectivity, including its possibilities in other sectors and its impact across broader economies.

Beyond the implications for industry, connectivity also has ramifications for equity and society. A picture of today's digital networks superimposed on the planet would confirm that the World Wide Web is not actually worldwide today. There are dark gaps as well as regions of unusual density. In the decade ahead, many of those blank spaces will light up, and billions of new users will come online.

Enabling more people to plug into global flows of information, communication, and services could add another $1.5 trillion to $2 trillion to GDP, above and beyond the economic value of the use cases identified in the four commercial domains highlighted in this research. Although gaps will remain, this trend could unlock greater human potential and prosperity in many developing nations.

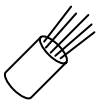
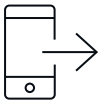
In the decade ahead, a combination of technologies will take important strides forward

Connectivity is undergoing evolutionary change in most parts of the world—and, in select areas, a genuine leap into the frontier.

Existing connectivity technologies are expanding their reach as networks are built out and adoption grows. At the same time, the next generations of these technologies are appearing, with upgraded standards (Exhibit E1). Both of these trends are expanding and improving what we refer to as "advanced connectivity." In addition, a new type of more revolutionary (and more capital-intensive) "frontier connectivity" is emerging, although it is likely to have a more limited geographic footprint in the decade ahead, barring the mass-market deployment of satellite coverage.

Exhibit E1

Connectivity technologies are taking strides forward.

	Connectivity spectrum		Value proposition
Frontier		LEO constellation	Global coverage with significantly reduced latency vs. existing satellite offerings
		High-band 5G (ie, millimeter wave)	Highest speed, low latency, and highly secure cellular connectivity
Advanced		Low- to mid-band 5G	High-speed, low-latency cellular connectivity overlay on existing 4G infrastructure
		Wi-Fi 6	Next-generation Wi-Fi with improved speed, device density, and features to increase device efficiency
		Fiber/DOCSIS 3.x	High-speed, low-latency fixed networks that support other connectivity
		LPWAN (e.g., NB-IoT, Sigfox, LoRa)[1]	Low-power and low-maintenance networks that support high densities of connected devices
		Short range (eg, RFID/Bluetooth)	Short-range and efficient device-to-device connectivity, storage, and identification

1. LPWAN are low-power, wide-area networks; NB-IoT refers to narrow-band Internet of Things.
Source: McKinsey Global Institute analysis

— **Advanced connectivity:** Existing connectivity technologies continue to proliferate and evolve, from backbone networks to the last mile that meets the end user. In networks, for instance, providers are upgrading existing 4G infrastructure with low- to mid-frequency

"non-standalone" 5G network overlay.[1] The results of these upgrades will vary significantly depending on the spectrum used and density of supporting infrastructure such as cell towers. But in general, these low- to mid-frequency 5G networks can offer significant improvements in speed and latency while supporting a greater density of connected devices. Meanwhile, fiber optic networks continue to expand, and the introduction of the new DOCSIS 3.x standard promises to bring the performance of cable broadband closer to that of fiber—and to do so over existing infrastructure. In the last mile of access, the next generation of Wi-Fi (Wi-Fi 6) will improve speeds while supporting many more connected devices. Technologies that use radio signals for tagging, tracking, and contactless short-range communication between devices (such as Bluetooth, NFC, and RFID sensors) are becoming more sophisticated. Low-power wide-area networks (LPWANs, with competing standards such as LoRa, NB-IoT, and SigFox) provide connectivity over broader areas and longer ranges. All of these technologies continue to improve in terms of affordability, functionality, and adoption.

— **Frontier connectivity:** Frontier technologies like high-band 5G and low-earth orbit satellite constellations represent a more radical departure.[2] Designed to be the most ultra-fast mobile option, high-band 5G (often in the form of standalone 5G) promises to put the speed, latency, reliability, and security of fiber in the air, expanding what mobile devices can do. It offers a significant step change in overall network performance from low- to mid-band 5G. Low-earth orbit (LEO) satellites could also deliver a breakthrough—not necessarily in network performance but in breadth of coverage. By essentially beaming broadband down from space, they could bring coverage to remote parts of the world where the economics do not work for laying fiber or building cellular towers. However, providing ubiquitous coverage requires a constellation of many satellites orbiting at once, making viability uncertain. OneWeb and SpaceX are the only companies to launch test satellites (as of this writing), and no commercial services are yet available.

The advances described above are occurring alongside an expansion of hardware and software capabilities.[3] Cloud computing will provide a processing backbone and storage capacity for use cases that require significant computational power. Edge computing will do the same while removing latency limitations. The new architecture of connectivity will also include private corporate networks. These connectivity and computing advances will enable cheaper and much more efficient "thin" devices connecting with the cloud and localized servers; they could become mainstream at the end of the decade for both consumers and businesses.

Advanced and frontier connectivity will enable new capabilities in major commercial domains

Today consumers still power the internet. Online video accounts for some 70 percent of the world's internet traffic, with only small differences across regions. By 2030, we expect that share to exceed 80 percent. By some estimates the world will consume 20 times more data than it does today, with much of this growth driven by new users, more time spent watching video, and higher-definition content.[4]

Connectivity will enable businesses to do more in the next decade as well.[5] Enhanced broadband will make streaming, downloads, and data exchange lightning fast. Because they

1 "Low- to mid-band" refers to the use of frequencies between 600 MHz and 6 GHz, which offer a good balance of throughput, capacity, and coverage. "Non-standalone" 5G refers to the use of an existing LTE network for signaling and network-control functions, with the 5G component exclusively focused on user traffic. In contrast, "standalone" 5G refers to a network that uses 5G cells for both signaling and information transfer.

2 "High-band" refers to the use of frequencies above 24 GHz (also referred to as millimeter-wave spectrum), which offer the ultra-high broadband speed envisioned for 5G.

3 "New demand, new markets: What edge computing means for hardware companies," McKinsey.com, November 2018.

4 Based on Cisco's projections through 2022, and extended to 2030. For Cisco's 2022 projection, see *Cisco Visual Networking Index: Global mobile data traffic forecast update,* Cisco, February 2019.

5 "Are you ready for 5G?," McKinsey.com, February 2018.

require less power, LPWANs can extend the battery life of the devices and sensors they connect, making it viable for the Internet of Things to scale up like never before. Ultra-low latency and strong security will create the confidence to run "mission-critical" applications that demand absolute reliability and responsiveness—even in vital infrastructure systems and in matters of life and death. LEO satellites could provide true global coverage.

Based on industry-specific research and expert interviews, we have identified hundreds of use cases in commercial domains that would run on both advanced and frontier networks. These are independent of the many consumer-driven entertainment and internet applications that are possible. To convey the sheer diversity of use cases, as well as some of the opportunities and implementation challenges, we profile four commercial domains with some of the largest potential to capture higher revenues or cost efficiencies.[6] The use cases we describe in this research are meant to be illustrative rather than exhaustive, and others will likely emerge over time.

— Connectivity will be the foundation for increasingly intelligent **mobility** systems.[7] While the automotive industry is at the heart, mobility is a broader concept that includes car-sharing services, public transit, infrastructure, hardware and software, and more—in short, all of the actors and enablers involving in moving people (and goods) from one point to another on the ground. Connectivity could open up new revenue streams through preventive maintenance, improved navigation and carpooling services, and personalized "infotainment" offerings. Vehicle-to-infrastructure and vehicle-to-vehicle communications can prevent collisions, enable various levels of vehicle autonomy, and improve traffic flow. We estimate the GDP impact of connectivity in mobility to be $170 billion to $280 billion by 2030.

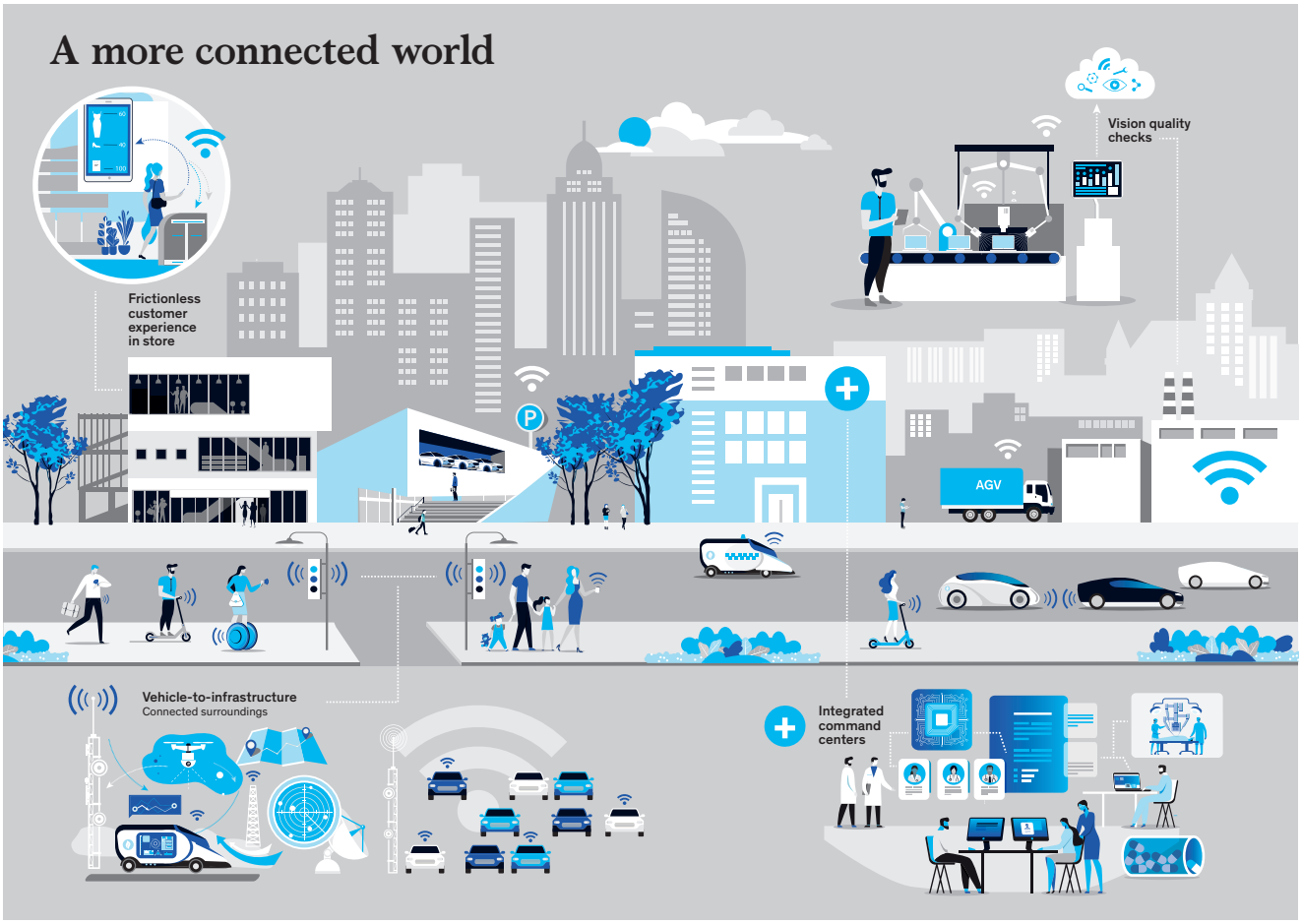
— Connected devices and advanced networks could transform **healthcare.**[8] Low-latency networks and high densities of connected devices and sensors make it possible to monitor patients at home in real time, which could be a major boon in the treatment of chronic diseases. Data can flow seamlessly throughout entire medical systems to smooth operations and coordinate care. AI-powered decision support tools can make faster and more accurate diagnoses, and many tasks can be automated so that caregivers can spend more time with patients. The ability to aggregate and analyze enormous data sets could yield new treatments. Together these use cases could free up additional investment capacity in healthcare and generate $250 billion to $420 billion in global GDP impact by 2030.

— **Manufacturing and other advanced industries** can run highly precise operations using low-latency and private 5G networks.[9] Smart factories powered by analytics, artificial intelligence, and advanced robotics can run at maximum efficiency, optimizing and adjusting processes in real time—not only on select assembly lines but across multiple plants. A growing number of factories will incorporate features such as automated guided vehicles and computer-vision-enhanced bin picking and quality control; these functions require the kind of speeds and ultra-low latency that high-band 5G networks provide. The GDP impact of connectivity in manufacturing could reach $400 billion to $650 billion by the decade's end.

— **Retailers** can use sensors, trackers, and computer vision to manage inventory, improve warehouse operations, and coordinate along the supply chain. Connectivity can support frictionless in-store experiences—for example, eliminating checkout and adding augmented reality for better product information. Real-time personalized

6 In addition to illustrating the range of use cases, these domains were chosen as a large, representative cross-section of the economy. They include both industrial and consumer-facing businesses, with a diverse mix of assets, occupations, and geographic footprints, and they span many different supply chains.
7 "The trends transforming mobility's future," *McKinsey Quarterly,* March 2019.
8 "The era of exponential improvement in healthcare?," McKinsey.com, May 2019.
9 "Five ways that 5G will revolutionize manufacturing," Operations blog, McKinsey.com, October 2019.

recommendations and promotions can increase sales. Some innovative retailers have already begun experimenting with and implementing some of these use cases, and advances in technology and affordability should lead to broader adoption by the decade's end. These use cases in retail could boost GDP by $420 billion to $700 billion.



Building a more connected world could create substantial economic value, mostly enabled by advanced connectivity

The use cases we identified in the four commercial domains described above could boost global GDP by an estimated $1.2 trillion to $2 trillion by 2030 (Exhibit E2). This would be equivalent to 3.5 to 5.5 percent of the expected GDP in these domains.

These use cases (and the capabilities related to enhanced broadband, the IoT, and mission-critical applications) are relevant in other domains as well.[10] Next-generation inventory management, for example, has applicability beyond retail; it also has value for logistics and consumer goods companies. Use cases that improve equipment utilization in factories also apply in mining, oil and gas, and commercial real estate operations. Over and above the value generated in the four domains described in this research, use cases running on advanced and frontier connectivity could generate trillions of dollars in value across the entire global economy.

There are additional economic benefits to businesses, consumers, and society that are not captured in this analysis. They include, for instance, the ability for businesses to differentiate themselves by creating a rich customer experience; the benefit of having better health

[10] On 5G specifically, several papers make the point that the economic potential is linked to business use cases and cross-industry relevance. See, for instance, *The road to 5G networks: Experience to date and future developments*, OECD Digital Economy Papers, No. 284, July 2019; and *The 5G economy: How 5G technology will contribute to the global economy*, IHS Economics and IHS Technology, January 2017.

outcomes and healthier, more productive citizens; and the ability to reduce waste and better manage capital and natural resources in production processes.

In the four domains we studied, advanced connectivity can enable some 70 to 80 percent of the economic potential. A great deal can be achieved without investing in frontier connectivity. This is because even in the wealthiest economies, only a relatively limited set of leading companies are deploying the most ambitious use cases that can run even on today's networks, from sensor-enabled inventory management to logistics tracking. As connectivity improves and hardware and applications become more affordable and mainstream, there is much more room for adoption to spread across domains, driving bigger productivity gains.

By contrast, use cases that require frontier connectivity such as high-band 5G could eventually generate some 20 to 30 percent of the potential impact, based on the use cases we have sized. High-band 5G will create greater network efficiency, boosting speeds and lowering latency even as providers accommodate more consumer-driven traffic and more devices. Existing use cases can run on a bigger scale while becoming more sophisticated and reliable. For example, these capabilities could open the doors to deploying tens of thousands of infrastructure sensors in a dense urban area, streaming data to consumer vehicles and public institutions securely in real time to enable safety features and faster emergency response.[11] It is possible that the value of use cases running on frontier connectivity could exceed our estimates, depending on whether some high-potential but still speculative use cases like augmented reality and self-driving vehicles reach mass adoption by decade's end. A stronger digital backbone can also support new applications we cannot predict today. The extent to which these developments—and the related demand—actually materialize will likely have a meaningful impact on the deployment and adoption of frontier connectivity.

In addition to the potential in these four commercial domains, advances in technology, coverage, and affordability can bring more of the world online. Aging or inadequate networks will be upgraded in future investment cycles, while new digital networks will reach some regions for the first time. Today 40 percent of the global addressable adult population is still under-connected (in other words, not yet using 3G-capable data networks or better) or altogether offline due to inadequate coverage, affordability barriers, or insufficient relevance (such as content in the local language). By 2030, that share could be cut in half. This will be enabled by a combination of trends, including not only wider network coverage but also the growing affordability of devices and data plans, the development of more relevant internet content, and demographic and social shifts (like increasing urbanization rates). This newly online population will benefit from intermediate connectivity via 3G or 4G/LTE cellular networks for basic web browsing, consumer mobile phone applications, e-commerce, and online video.[12] Global GDP could increase by another $1.5 trillion to $2 trillion as a billion people gain better access to digital information, tools, and services.

[11] *Smart cities: Digital solutions for a more livable future*, McKinsey Global Institute, June 2018.

[12] We use the term "intermediate connectivity" to refer to access to 3G and 4G/LTE cellular networks (with speeds of 1 to 50 Mbps and latency of ~50 milliseconds or more). Compared to advanced and frontier connectivity that we defined previously, intermediate connectivity features different technical capabilities, supported applications, and subscriber populations.

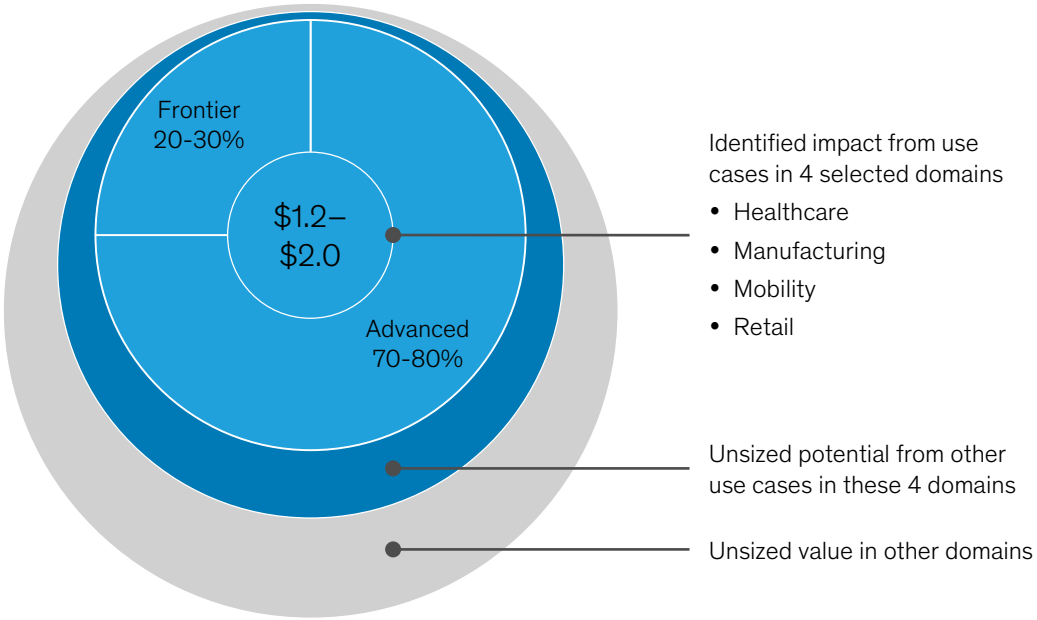
Exhibit E2

We analyzed use cases across four domains.

Connectivity will unlock value in these domains and beyond

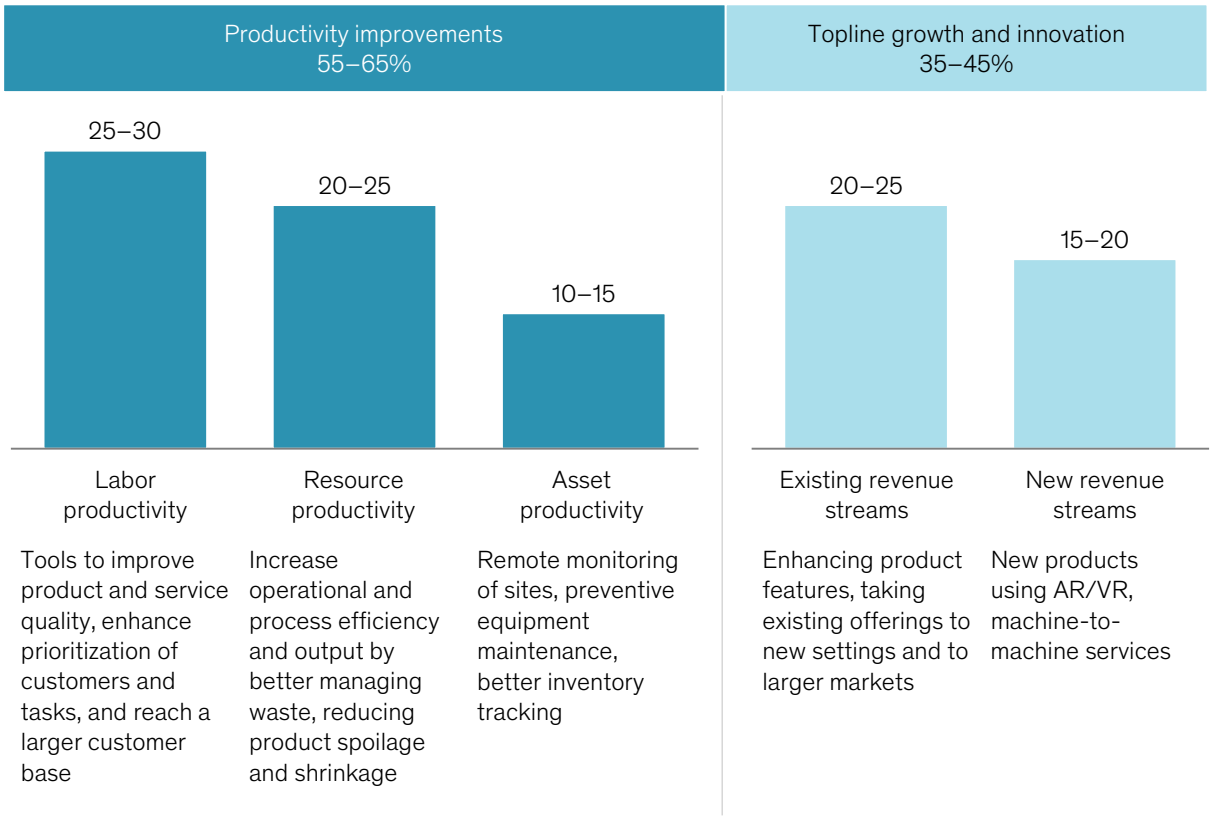
Projected GDP impact from enhanced connectivity, 2030

%; $ trillion



Breakdown of impact category on selected use cases (healthcare, manufacturing, mobility, and retail)

% of total use cases selected


Productivity improvements
55–65%
Topline growth and innovation
35–45%
25–30
20–25
10–15
20–25
15–20
Labor productivity
Resource productivity
Asset productivity
Existing revenue streams
New revenue streams
Example use cases
Tools to improve product and service quality, enhance prioritization of customers and tasks, and reach a larger customer base
Increase operational and process efficiency and output by better managing waste, reducing product spoilage and shrinkage
Remote monitoring of sites, preventive equipment maintenance, better inventory tracking
Enhancing product features, taking existing offerings to new settings and to larger markets
New products using AR/VR, machine-to-machine services

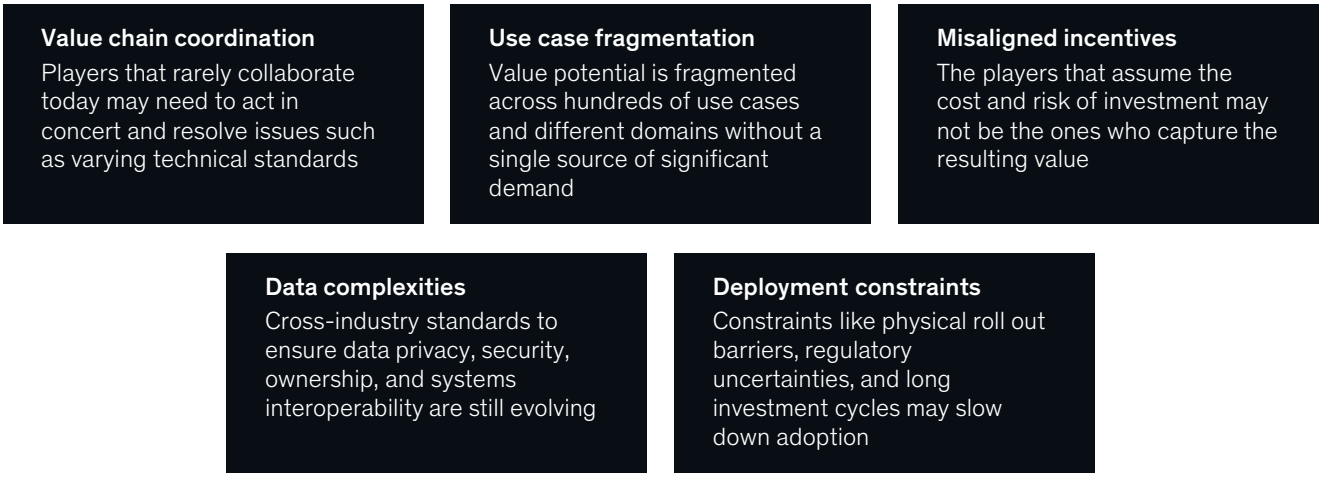
Note: Figures may not sum to 100% because of rounding.
Source: McKinsey Global Institute analysis

To realize the full value at stake, persistent issues need to be solved

The growth of connectivity is a development with substantial promise—and as noted above, most of it can be achieved using technology that already exists today. While this is grounds for optimism, progress has yet to take off. In a world where future economic growth depends on improving productivity, the hurdles slowing both connectivity investment and the widespread adoption of use cases urgently need to be addressed. While the barriers vary somewhat in each commercial domain that we analyzed, many of the issues can be categorized into five groups (Exhibit E3).

Exhibit E3

Longstanding hurdles continue to hold back the promise of connectivity.


Value chain coordination
Players that rarely collaborate today may need to act in concert and resolve issues such as varying technical standards
Use case fragmentation
Value potential is fragmented across hundreds of use cases and different domains without a single source of significant demand
Misaligned incentives
The players that assume the cost and risk of investment may not be the ones who capture the resulting value
Data complexities
Cross-industry standards to ensure data privacy, security, ownership, and systems interoperability are still evolving
Deployment constraints
Constraints like physical roll out barriers, regulatory uncertainties, and long investment cycles may slow down adoption

Source: McKinsey Global Institute analysis

— **Value chain coordination:** Multiple players across an ecosystem may have to cooperate in order to implement a given use case.[13] Many have never collaborated before, but they will need to work together on issues such as agreeing on technical standards. In mobility, for instance, vehicle-to-infrastructure and vehicle-to-vehicle warning systems involve public infrastructure providers, rival automotive manufacturers, connectivity providers, technology players, and equipment manufacturers. All must align on technical standards in the hardware for the system to work—but standards are still evolving, even in the most developed markets.

— **Use case fragmentation:** The value at stake from enhanced connectivity is substantial when viewed cumulatively across the entire economy, but it requires aggregating many small pockets of potential across hundreds of use cases and domain participants. Connectivity use cases are not always core priorities for participants, especially those who are not as far along in their digital transformation journey. All of this can contribute to companies taking a "wait-and-see" approach or stalling in never-ending "pilot purgatory." Retailers and manufacturers, for example, could both benefit from advanced computer vision, but the value it could produce may not be significant enough for companies in these sectors to create strong demand for someone to deliver these services right away. In such cases aggregators may be needed to create enough viable scale in demand.

— **Misaligned incentives:** This is the familiar monetization question. The actor assuming the cost and risk of investment (and doing the heavy lifting of implementation) in a domain may not be the one who captures the ultimate financial gain. In healthcare, for instance, several connectivity-enabled use cases have the potential to increase efficiency and improve health outcomes. But while hospitals and health providers may be the ones to make such

[13] "Management's next frontier: Making the most of the ecosystem economy," McKinsey.com, October 2017.

investments, train workers, and change their day-to-day operations, the financial benefits may accrue to health insurers or consumers. Similarly, consumer internet, media, and advertising companies have long profited from offering "over-the-top" services that run on networks built and maintained by connectivity providers, but the providers themselves have struggled to monetize this activity in a proportional way.

— **Data complexity:** Many use cases require data sharing across firm and industry boundaries. But standards to ensure privacy, security, ownership, and interoperability are still evolving.[14] Protecting data is paramount for both companies and consumers to guard against ever-evolving risks. In addition, machine-to-machine transmissions (for example, between a hospital's health informatics system and a patient's home health monitor, or between equipment in a remote production plant and an operations hub) requires interoperability between IoT systems.

— **Deployment constraints:** Some of the issues holding back progress include physical barriers slowing network enhancement and use case adoption. Connectivity providers and domain users alike may have an extensive legacy asset base that will be expensive to upgrade. Regulatory uncertainty also needs to be resolved around broad issues as well as domain-specific questions in areas such as mobility and healthcare. For connectivity providers, practical constraints like spectrum availability, access rights to public infrastructure, and power density limits are persistent challenges that often have to be overcome at the local level. Even among commercial customers such as retailers, manufacturers, or wholesalers, adopting connectivity-enabled use cases can be delayed by long capital investment cycles. In the past decade, many firms have postponed asset upgrades due to weak growth and an uncertain investment outlook.[15]

These are thorny issues that cannot be solved by technological advances alone. But they are also not insurmountable challenges. Fragmentation presents an opportunity for an actor—whether government, connectivity providers, tech giants, or industry coalitions—to play a coordinating role. Likewise, current business models may have to evolve to allow for more cross-sector partnerships, realignment of incentives, and risk sharing. In most countries, governments can play a coordinating role or set standards, but the private sector will shoulder most of the weight of forming smoothly functioning ecosystems.

The development of connectivity and the geographic distribution of economic value will be uneven

Even if the market issues described above are resolved, connectivity will not be uniform across different regions. Deployment will be influenced by each market's revenue potential, its existing telecom infrastructure, its urban density, and local market dynamics including competition and regulation. Connectivity providers' own ability to undertake and monetize major capital investment is crucial. Another consideration is the evolution of demand and its distribution across users, applications, and geographies. As a result of all these factors, the business case for deploying advanced connectivity, and especially frontier connectivity, looks very different across markets.

The evolution of connectivity will vary across four country archetypes

We define four country archetypes based on differences in revenue dynamics, such as average revenue per user and level of data usage; cost dynamics, such as the quality and extent of existing telecom infrastructure as well as urban density; and market dynamics, including differences in regulation and competition. Based on these characteristics, we classify countries as being pioneers, leaders, followers, or trailing in connectivity today. We consider China and India as two unique cases in addition to these four archetypes.

[14] *Unlocking the potential of the Internet of Things*, McKinsey Global Institute, June 2015.
[15] "The road to 5G: The inevitable growth of infrastructure cost," McKinsey.com, February 2018.

The countries that are out in front today can continue to expect superior performance and new capabilities that may remain out of reach for years for the countries that trail in connectivity today (Exhibit E4). The countries that stay in the forefront of connectivity could have a first mover's advantage and position themselves to be the innovators.

These four sets of countries are progressing along the connectivity continuum at varying speeds and are likely to continue to do so:

— **"Pioneers,"** including the United States, Japan, and South Korea, have consistently led the pack in connectivity. They are already beginning to deploy high-band 5G networks in cities, taking advantage of mature fixed infrastructure and the relatively strong capital positions of their providers. In these markets, competitive dynamics are forcing providers to race ahead.

— **"Leaders,"** typified by markets such France, Germany, and the United Kingdom, are consistently close behind the pioneers. But operator investment may be constrained in these markets since price competition has reduced margins.

— **"Followers,"** such as Brazil, Poland, and Turkey, are starting with less adept infrastructure, and their providers will find it hard to support the large capital investment needed to build more sophisticated networks. They are expected to lag a few years behind in deployment, especially for frontier connectivity, which will likely be limited to major urban cores only.

— **"Trailing"** markets, such as Pakistan, Bolivia, and many African nations, are unlikely to gain widespread advanced or frontier connectivity in the near term. Although LEO satellites may provide connectivity options in these markets (and in rural areas of follower markets), the cost of deployment and the affordability of user devices will be limiting factors.

In addition to the four archetypes above, China and India retain their unique status:

— **China** has poured huge investment into its fixed and cellular networks for the past several years. It is building out this backbone at a faster rate than any other country, with the aim of offering 5G in all major cities and switching a quarter of mobile subscriptions to 5G by 2025.

— **India** is digitizing faster than any trailing market. Although it is rapidly modernizing mobile networks, they are likely to have performance limitations outside of a few major cities. The country's connectivity providers have come under pressure from price wars, and it will likely take price increases or government action to spur buildout.

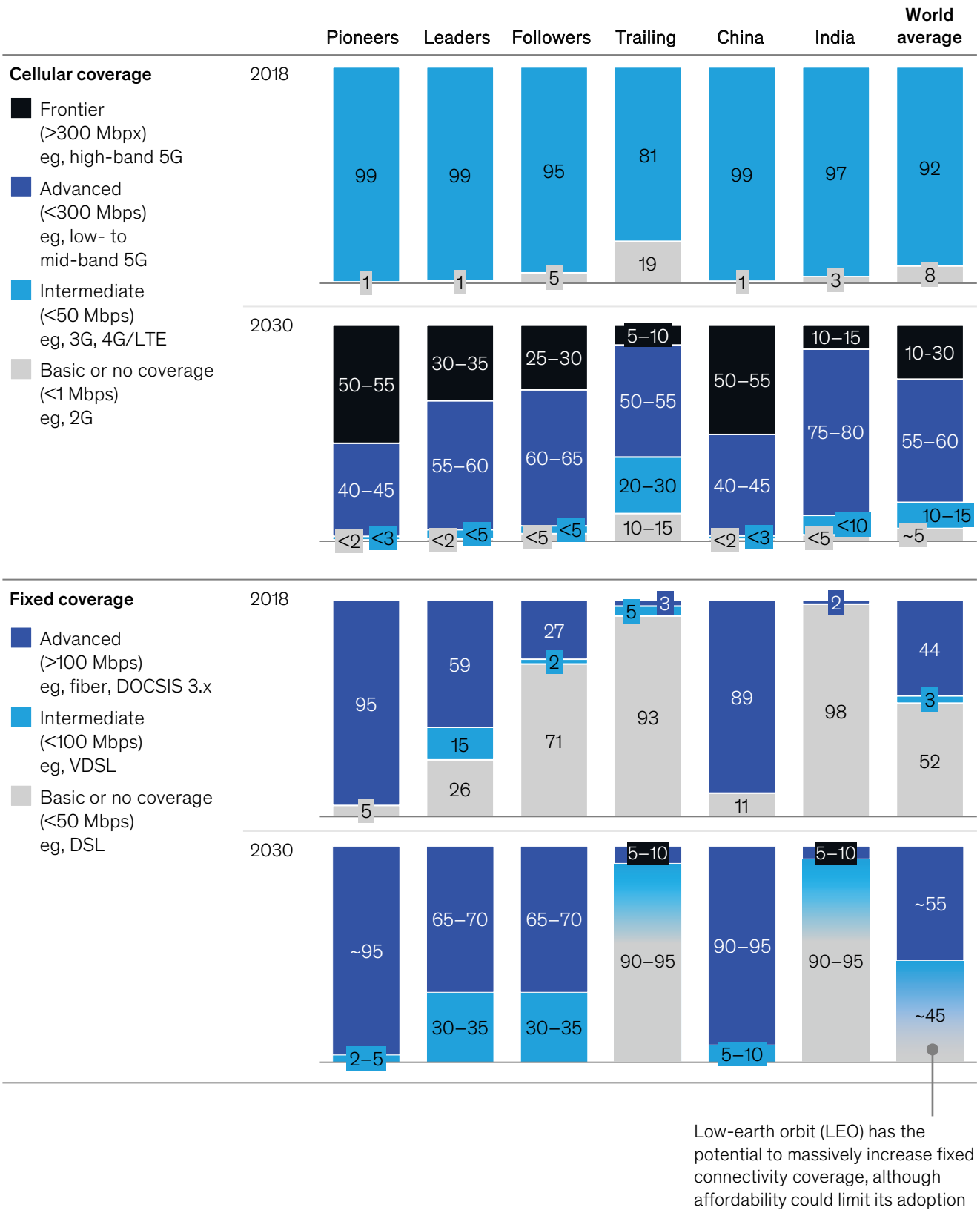
Over the next decade, connectivity providers will continue to build and upgrade networks, but the rate of progress will vary across these archetypes, with pioneers and China consistently leading the pack.

Advanced connectivity—in particular, advanced connectivity that relies on mobile networks, in the form of low- to mid-band 5G coverage—could reach as much as 80 percent of the global population by decade's end. This would come at a cost of some $400 billion to $500 billion. Yet significant gaps will remain. While coverage rates might exceed 90 percent in most of the world, they will likely reach only around 60 percent on average in trailing countries.

Exhibit E4

Connectivity divides between country archetypes are likely to widen.

% of population



Note: Figures may not sum to 100% because of rounding.
Source: McKinsey Global Institute analysis of data from GSMA Intelligence; iDate; Analysys Mason; Ovum; *The Economist*; United Nations; World Bank; WCIS; National Census Bureaus; corporate annual reports and press releases

Advanced connectivity that relies on fixed networks is a different story. Today, pioneer countries and China enjoy very high fiber coverage rates relative to the rest of the world, due in large part to various private- and public-sector investments. In the years ahead, connectivity providers may not have a strong business case to expand fiber coverage further in many markets without subsidies from governments or other third parties. Without additional investment, fiber coverage is not likely to grow substantially in many parts of the world, although it could more than double in follower markets as they pursue catch-up growth. Overall, we estimate that fiber coverage rates could reach 90 percent or higher in pioneer markets and China, 65 to 70 percent in leader and follower countries, and 5 to 10 percent in trailing markets and India by 2030.

Frontier connectivity (that is, high-band 5G) drives the required investment much higher, creating a tougher business case to do so on a comprehensive scale. Yet in certain dense urban areas with very high per capita data consumption, providers may find that the network efficiency benefits alone justify deployment. Covering roughly a quarter of the world's population by the decade's end would require some $700 billion to $900 billion. While China and pioneer markets are projected to cover up to 55 percent of their populations, the corresponding share is projected to reach 35 percent in leader markets, 30 percent in follower countries, and 10 to 15 percent in trailing markets and India.

Despite the fact that huge populations stand to gain coverage for the first time, the digital divide that separates urban and rural populations and trailing countries from the rest of the world appears likely to persist in the decade ahead. If LEO satellites are successfully deployed, they have the potential to change the game and almost erase the gap. Yet they remain a wild card—and other barriers such as readiness and the affordability of devices and data plans would need to be addressed in addition to coverage.

Where will the value associated with these use cases flow?

Some $1.2 trillion to $2 trillion is at stake in mobility, healthcare, manufacturing, and retail alone. But the pie will not be divided evenly across country archetypes (Exhibit E5).[16] These differing outcomes stem from the expected availability of advanced and frontier connectivity—and the coverage gap will be especially pronounced for frontier connectivity.

In terms of advanced connectivity use cases, we estimate that 60 to 65 percent of the value could go to pioneer markets and China, 20 to 25 percent to leader markets, 10 to 15 percent to followers, and 5 percent to India and trailing countries.[17] The share going to China and pioneers would slightly exceed their expected weight in the global economy in 2030, while the share going to India and trailing markets would fall below. Leader and follower markets stand to make gains that are largely in line with the share of global GDP they are expected to generate.

For use cases running on frontier connectivity, the dispersion of value is more striking. We estimate that 70 to 75 percent would go to China and pioneer markets, 15 to 20 percent to leaders, 5 to 10 percent to followers, and only 2 to 5 percent to India and trailing countries. China stands to capture an outsized share that could be 40 to 50 percent higher than its share of global GDP, while the share going to pioneer markets could be 20–30 percent higher. The story is not as positive for the rest of the world. Leaders might capture a share that is 20 to 30 percent lower than what the expected size of their economies would indicate. Followers might punch 30 to 40 percent below their weight, while trailing countries and India could capture a share of the anticipated value that is 70 to 80 percent below their share of global GDP.

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16 We estimate this distribution based on each archetype's GDP share, its current and expected evolution of fixed and wireless connectivity, its urban density, and the demand for use cases and their economic viability in the region.

17 It should be noted that significant value and GDP gains are possible in India and trailing markets from a range of use cases enabled by the expansion of intermediate connectivity, along with foundational digital identification infrastructure and digital payment systems. See *Digital India: Technology to transform a connected nation*, McKinsey Global Institute, March 2019; and *Digital identification: A key to inclusive growth*, McKinsey Global Institute, April 2019.

Exhibit E5

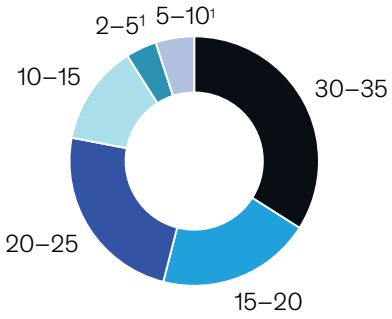
The value produced by use cases running on advanced and frontier connectivity could be distributed unevenly.

2030

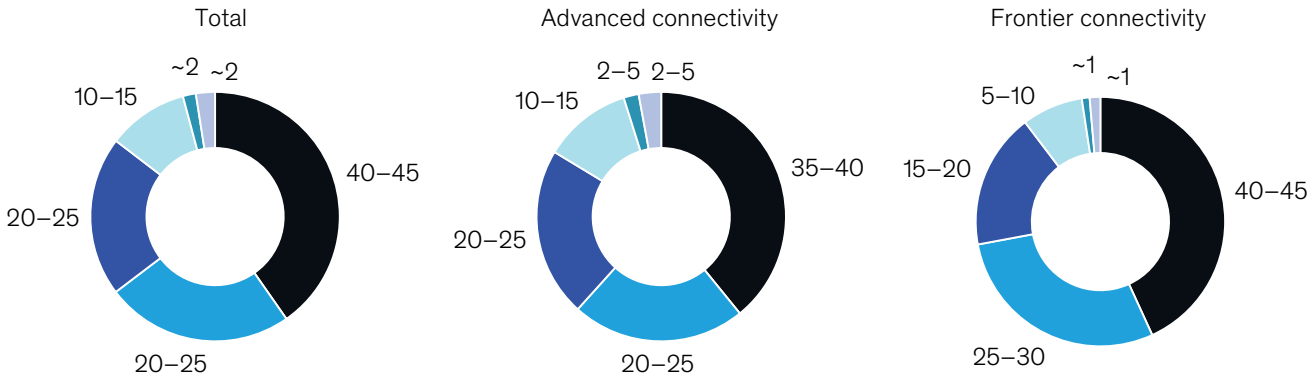
%

Pioneer | China | Leader | Follower | Trailing | India

Projected global GDP contribution by country archetype



Distribution of GDP impact of connectivity-enabled use cases



Note: Figures may not sum to 100% because of rounding.

1. The relatively low shares in India and trailing markets could be offset by a range of use cases enabled by the expansion of intermediate connectivity, as well as foundational digital identification infrastructure and digital payment systems.

Source: McKinsey Global Institute analysis of data from GSMA Intelligence; iDate; Analysys Mason; Ovum; *The Economist*; UN data; World Bank; World Cellular Information Service; IHS Markit Global Industry Service; national census bureaus

Unlike the value produced within commercial domains, approximately half of the $1.5 trillion to $2 trillion associated with bringing a larger share of the population online could be concentrated in India, trailing countries, and follower countries. This is because the affordability and network availability gaps that can be closed over the next decade are most prevalent in these types of countries. An additional one-third would stem from China.

Providing connectivity is a tough business that could get tougher

The question of how to monetize usage has dogged connectivity providers (notably telecom operators) in previous technology cycles, and now the same issue threatens to carry over into the next. It will not be resolved solely through investing in new networks. Those networks will create major opportunities, but it will take new strategies to capture them.

The road for many connectivity providers has been rocky in recent years, and it does not look much smoother in the decade ahead. Build-outs and upgrades will demand major investment at a time when mature markets are saturated, and competition is leading to price wars. Many providers will struggle to find the required capital and make investments pay off with conventional revenue models. In some countries, competitive pressures or regulation are forcing connectivity providers to plunge ahead with buildouts and upgrades even before the economics have become clear.

Connectivity providers that have already invested heavily in laying digital infrastructure foundations will likely be able to maintain stable ratios of capital investment to earnings even as they continue with their rollouts. But the pressure will be acute for those that have not yet invested heavily and now find themselves facing a game of catch-up with new technologies. Those outside of pioneer markets and China will collectively need to find significant additional annual revenue growth to deliver adequate returns to their shareholders while continuing to cover the costs of advanced connectivity upgrades—let alone frontier networks.

Our research raises more questions about the future of connectivity

Our research to date has surfaced a number of questions and uncertainties that require further investigation.

First, as connectivity providers face the need to sustain major capital investment, what kind of new business models might emerge? Can providers form partnerships to share the costs of deployment? Network sharing has proven successful with previous generations of cellular connectivity, and it could reduce the cost of 5G deployment.[18] Further, can providers partner with businesses in other domains to create viable long-term strategies, potentially taking a bigger role in developing innovations such as connected vehicles, remote healthcare, or the Internet of Things?

A second set of questions revolves around what types of new players might become connectivity providers, from tower and infrastructure companies to tech giants. To what extent will companies across industries opt to build their own private networks, and who will own that space? How likely is it that today's traditional telecom operators will continue to provide the backbone of connectivity architecture for years to come? What about in the "last mile" of connectivity services? LEO satellites in particular remain a wild card; it is still unclear if their offerings will gain traction and become profitable. If so, they could dramatically expand capacity and intensify pricing pressure throughout the industry.

Beyond infrastructure implications for connectivity providers, the broader technical architecture is changing within specific domains. Enhanced connectivity may open opportunities to rethink where and how computing happens, especially when combined with advances in computing (such as cloud, edge, and quantum computing), device and sensor efficiency, storage, and software design. Connectivity providers and technology companies alike are already hurrying to identify potential new offerings, as evidenced by Amazon and Verizon's recent 5G Edge computing partnership.[19] These changes could have meaningful implications for the full technical stack of companies and across entire domains.

Another set of questions relates to consumers. Consumer media and entertainment accounts for most of the capacity usage—yet the demand is skewed by a small share of consumers, and providers have had a hard time monetizing this usage. Will this trend continue, or will new applications change this dynamic? The research suggests that 2 billion new consumers will come online over the next decade. Will they follow the same pattern?

[18] "Network sharing and 5G: A turning point for lone riders," McKinsey.com, February 2018.
[19] Brian Heater, "Verizon and AWS announce 5G Edge computing partnership," TechCrunch, December 2019.

A related area, which we will explore in future research, centers around use cases in other commercial domains. How much more economic value can they generate? How different are their use cases from the ones considered in this research, and can most of them similarly be executed using currently available technologies? Beyond the barriers to adoption identified in this research, do other domains have additional, specific issues due to their market dynamics, incentives, or regulations?

Lastly, the role policy makers will take in shaping the connected world of the future remains unclear. To date, governments around the world have taken markedly different approaches in facilitating the expansion and evolution of connectivity. In some markets, governments have played a very hands-on role through direct investment and subsidies for connectivity providers. Some are investing heavily in R&D. Others are taking a more hands-off role, simply facilitating the broader connectivity market through actions like spectrum auctions. In addition to these levers, regulations on topics such as spectrum sharing and power density will have major implications for where, when, and how the value of enhanced connectivity will be realized.

Advanced and frontier connectivity will give companies in every domain a powerful new platform for innovation and productivity. The full range of new use cases that can be developed on top of this digital backbone will become apparent in the decade ahead, including some that we cannot imagine today. Turning all of this potential into reality depends on whether connectivity providers, end users in multiple domains, and public officials can forge new models and clear away some of the barriers. The world could soon be more connected—setting the stage for both innovation and disruption along the way.

1. Changing how the world connects

The days of dial-up, when the internet moved at a glacial pace, are now a distant memory. Today technology heeds our commands at the touch of a button. But even in the wealthiest countries, the digital world is not as fast and responsive as it could be. Calls still drop, connections go down, large files fail to download, and videos freeze for buffering.

All that is about to change, and quickly, thanks to the next generations of fixed and mobile connectivity as well as the proliferation of some existing technologies. More than any single advance on its own, it is the convergence of these developments that could enable new capabilities and create a more connected world.

In the coming years, connections could be 10 times faster, with a new level of reliability and stability.[20] As latency improves by up to 50 times, applications will respond seamlessly to commands. Consumers could enjoy instant high-definition video streaming and even new types of immersive experiences with augmented and virtual reality.

Improved connectivity will provide a platform for every domain to boost productivity and innovate, running a remarkable diversity of applications. Adding up use cases across all domains, we see trillions of dollars in untapped potential—and a great deal of it does not require waiting for the most capital-intensive mobile networks to be built.

The spread of advanced connectivity technologies with stronger capabilities, as well as the debut of frontier connectivity, will have significant implications for the way we communicate, do business, and consume entertainment and information. The rest of this report will consider trends and scenarios in demand, capital investment, and rollout. It will also preview use cases in mobility, healthcare, retail, and manufacturing to illustrate what businesses can do on top of this backbone. The world's connections are set to branch out, extending to more people, places, and devices, across more geographies, than ever before.

Connectivity technologies are taking strides forward

The world's connections are about to expand and improve rapidly in the years ahead, making it possible for users to run more sophisticated applications. While the debut of ultra-high-speed 5G networks has commanded a great deal of attention, a quieter but still-powerful evolution has been taking place. We distinguish between two types of connectivity: advanced and frontier (Exhibit 1). See also Box 1, "What is possible with advanced and frontier connectivity?," for more on the types of capabilities each one supports.

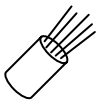
Advanced connectivity

Existing connectivity technologies are penetrating more broadly across geographies and domains. At the same time, the newest standards are making them more robust.

[20] *IMT vision: Framework and overall objectives of the future development of IMT for 2020 and beyond*, International Telecommunications Union, ITU-R M.2083-0, September 2015.

Exhibit 1

Connectivity technologies are taking strides forward.

	Connectivity spectrum		Value proposition
Frontier		LEO constellation	Global coverage with significantly reduced latency vs. existing satellite offerings
		High-band 5G (ie, millimeter wave)	Highest speed, low latency, and highly secure cellular connectivity
Advanced		Low- to mid-band 5G	High-speed, low-latency cellular connectivity overlay on existing 4G infrastructure
		Wi-Fi 6	Next-generation Wi-Fi with improved speed, device density, and features to increase device efficiency
		Fiber/DOCSIS 3.x	High-speed, low-latency fixed networks that support other connectivity
		LPWAN (e.g., NB-IoT, Sigfox, LoRa)[1]	Low-power and low-maintenance networks that support high densities of connected devices
		Short range (eg, RFID/Bluetooth)	Short-range and efficient device-to-device connectivity, storage, and identification

1. LPWAN are low-power, wide-area networks; NB-IoT refers to narrow-band Internet of Things.
Source: McKinsey Global Institute analysis

In terms of mobile coverage, providers are upgrading existing 4G infrastructure with low- to mid-band 5G network overlay. The end results of these upgrades will vary depending on the spectrum used and tower density. But in general, these low- to mid-frequency 5G networks can offer significant improvements in speed and latency, all while supporting a greater density of connected devices.[21] On the fixed side, fiber optic networks continue to expand. The introduction of the new DOCSIS 3.x standard also promises to bring the performance of cable broadband closer to that of fiber—and to do so over existing infrastructure.

Once a location is wired with fiber, the next generation of Wi-Fi (Wi-Fi 6) will improve speeds while supporting many more connected devices. Wi-Fi 6 will make the biggest difference in crowded environments such as airports, apartment buildings, theaters, stadiums, public spaces, and homes with multiple internet users and smart gadgets. It also extends the battery life of smart devices and IoT sensors by employing "target wake time," which recognizes higher data transmission times instead of continuously scanning for signals. Users need to have Wi-Fi 6-ready devices, however.

[21] Low- to mid-band 5G can achieve speeds ranging from 100 to 300 Mbps, while latency can be reduced below 50 milliseconds. This type of 5G network is sometimes referred to as "non-standalone."

Technologies such as Bluetooth, NFC (near-field communication), and RFID (radio frequency identification) rely on radio signals. In rough terms, RFID enables one-way contactless communication between devices, while NFC is a newer form that can support close-range two-way communication. RFID is already widely used in logistics, while NFC is still emerging. Bluetooth enables data exchanges between fixed and mobile devices using radio waves and building personal area networks. These technologies have applications such as package tracking, security access, contactless payment, and sharing from one phone to another.

Low-power wide-area networks (LPWANs) provide connectivity over broader areas and longer ranges.[22] Different protocols, such as LoRa, NB-IoT, and SigFox, compete in this realm, with no clear winner at this stage.[23] Since LPWANs require less power from the devices they connect, they could enable batteries in those devices to last 10 years or more.[24] This could set the stage for billions of additional battery-powered devices and sensors to come online. Beyond network developments, IoT sensors themselves are becoming more sophisticated and robust. They can perform more complex tasks, from location tracking and temperature measurement to small-scale processing. Even as they gain capabilities, unit prices are rapidly declining.

Frontier connectivity

Frontier technologies like high-band 5G and low-earth orbit satellite constellations represent more radical departures.

High-band (also known as millimeter-wave or standalone) 5G networks represent a step change in performance.[25] Designed to be the most ultra-fast mobile option, high-band 5G promises to put the speed, latency, reliability, and security of fiber in the air, expanding what mobile devices can do.[26] Because this requires a highly densified radio access network, an upgraded 5G core network, and upgraded network support systems, these networks are highly capital-intensive to build.[27] Users will also need to upgrade to 5G-capable devices in order to experience the full benefits. Some companies will connect to commercially available services, while others may opt to build their own private 5G networks.

Like 5G, LEO satellites enable other technologies, but their viability is less certain.[28] If successful, they could deliver a breakthrough—not necessarily in network performance but in breadth of coverage. They could cover parts of the world where the economics do not work for laying fiber or building networks of towers (although providing coverage requires a constellation of many satellites orbiting at once). LEO satellite constellations could potentially substitute for mobile backhaul in disadvantaged or remote areas, essentially beaming broadband down from above, and providing coverage to those who lack connectivity today. The next generation of LEO satellite constellations promise substantial improvements over versions launched in the 1990s. However, OneWeb and SpaceX are the only companies to launch test satellites (as of this writing), and no commercial services are yet available.[29]

Cloud and edge computing will also be major elements of the new connectivity architecture

Improvements in connectivity are not happening in isolation. New and upgraded networks will enable and be used in conjunction with other key technologies—most notably cloud and edge

22 *Mobile IoT in the 5G Future*, GSMA Intelligence, April 2018.
23 "The future of connectivity: Enabling the Internet of Things," McKinsey.com, November 2017.
24 Dhaval Patel and Myounggyu Won, *Experimental study on low power wide area networks for mobile Internet of Things,* paper presented at the 2017 IEEE 85th Vehicular Technology Conference, 2017.
25 Standalone 5G refers to using 5G cells for both signaling and information transfer. It includes the new 5G Packet Core architecture instead of relying on the 4G Evolved Packet Core. Low- to mid-band 5G refers to deployment that depends on the control plane of an existing LTE network for control functions, while the 5G component is exclusively focused on the user plane.
26 High-band 5G offers speeds above 300 Mbps with less than 1 millisecond latency.
27 *2025 Capex outlook financing the 5G era*, GSMA Intelligence, April 2019.
28 "Emerging challenges for satellite spectrum monitoring," *ITU News Magazine*, November 2019.
29 "Before 2020 is over, SpaceX will offer satellite broadband internet," The Motley Fool, January 2020.

Box 1.

What is possible with advanced and frontier connectivity?

Later in this report, we look through the lens of a few commercial domains to describe some of the use cases that become possible when advanced and frontier networks are put in place.

Advanced connectivity technologies will offer a range of use cases generating efficiencies and value. In mobility, for example, cars will be able to connect and "talk" to each other in real time, thanks to short-range connections as well as low- to mid-band 5G. These live flows of data could help prevent collisions while smoothing the flow of traffic. Large transit hubs like airports will be able to provide fast, reliable Wi-Fi 6 to thousands of travelers at once, with optimized power consumption.

Frontier connectivity technologies come into play with use cases that demand more in terms of speed, volume of transmitted data, latency standards, and density of connections. In manufacturing settings, for example, automated machinery and vehicles, robots, and sophisticated user devices such as augmented reality headsets will run on lightning-fast high-band 5G, or a private network equivalent, to adapt the production environment dynamically. LEO satellites can provide coverage to otherwise difficult-to-cover areas, supporting new use cases in logistics and agriculture, for example. They could also serve as the primary connectivity solution for the aviation and maritime industries.

computing. Together these advances will enable some of the most data-hungry applications of the future.

Cloud computing will continue to provide a processing backbone for use cases that require high computational power, storage capacity, and advanced data analytics capabilities. This computing is essential for everything from storing videos to training artificial intelligence programs. Without a boost from cloud computing, user devices might not be able to run the most cutting-edge applications enabled by enhanced connectivity—or they would need to be far more expensive.

Edge computing aims to address some of cloud computing's limitations on several fronts.[30] Instead of transmitting data to central cloud servers that could be located hundreds or even thousands of miles away from the end user, edge computing brings computational power, storage, and networking closer to the physical location where the data is being generated or consumed.[31] The actual computing could then occur in smaller-scale data centers on the outskirts of major cities (the metro edge), at the base of radio access network base stations (the micro edge), in wiring closets on the end user's own premises (the edge gateway), or even on the device itself that generates data (the edge device).

Several trends are fueling the desire to bring processing and storage closer to the end user. The first is the proliferation of connected devices, especially as the Internet of Things is deployed in more environments. According to a recent IDC estimate, there could be up to 42 billion connected IoT devices by 2025.[32] These devices are also becoming more complex, evolving from basic smart devices to smart connected systems and processes. With a greater number of more complex devices comes an exponential increase in the amount of data being

30 *Establishing the Edge: a new infrastructure model for service providers*, Cisco, 2019.
31 *New demand, new markets: What edge computing means for hardware companies*, McKinsey & Company, November 2018.
32 *Worldwide global DataSphere IoT device and data forecast, 2019-2023*, IDC, May 2019.

generated—one that could exceed what a centralized cloud can absorb, especially as IoT applications rely more heavily on ultra-high-definition video and audio processing. This, in turn, creates a proportional need for efficient storage that ensures data security.

Another key driver in the growth of edge computing is the demand for real-time analytics, decision making, and adjustments. These capabilities are critical for applications such as augmented and virtual reality, connected cars, drones, video monitoring, and remote control of industrial machinery. This need for the most minimal of latencies makes it advantageous to avoid transmission time back to the cloud.

In addition, application development is shifting toward new solutions like container-first architecture, microservices architecture, and serverless computing platforms.[33] These solutions offer lightweight and portable alternatives for running applications on the edge, enabling developers to conduct testing and maintenance faster and more effectively. Finally, edge computing answers a critical need from industrial players operating transportation and logistics networks or remote factories. Now they can access computing, storage, and analytics resources in environments with intermittent or limited connectivity or even extremely remote areas.

All of these drivers point to growing adoption of edge computing worldwide. While it took 10 to 15 years for cloud computing to reach maturity, edge computing is on a faster trajectory.[34] The cloud ushered in a paradigm shift that changed software and computing power from products that are owned to services that are delivered. Edge computing could be viewed as an extension of this evolution towards a more decentralized model. Today much of the focus is on figuring out the architecture (particularly emerging industry standards for application development and maintenance, and for interoperability between the edge, devices, and the cloud). Once it emerges, adoption could rapidly accelerate.

Investment in this new processing layer is likely to be supported by players across the broader connectivity ecosystem.[35] Providers can benefit from the presence of an edge computing layer to increase the efficiency of their networks through centralized radio access networks (C-RAN), to deploy private networks for corporate customers, and to offer innovative services such as network slicing. For hyper-scale cloud providers like Amazon Web Services, Google Cloud, and Microsoft Azure, edge computing is an opportunity to expand their cloud offerings for a higher quality of service at lower cost. Co-location providers like Equinix and Digital Realty can lease additional capacity to their customers and expand their market shares by setting up more data centers. Network equipment manufacturers can further pursue the market for end-to-end private wireless network solutions, either independently or in partnerships with connectivity providers.

Technologies and their increasing affordability will put greater capabilities into the hands of more users

It is useful to think of connectivity as a continuum, with multiple stages: basic, intermediate, advanced, and now frontier.[36] Each stage reflects improvements in both speed and latencies, and other benefits (such as energy and spectral efficiency, and the density of connected devices that can be supported). Advanced and now frontier connectivity are setting a new

33 "Ten trends redefining enterprise IT infrastructure," McKinsey.com, November 2017.
34 Forrester Research, "Predictions 2020: Edge computing makes the leap," ZDNet, December 2019.
35 Solving edge computing infrastructure challenges, Schneider Electric, April 2019
36 Basic connectivity involves sunsetting technologies such as 2G cellular, dial-up, and L-band LEO satellites. Intermediate connectivity can be provided by 3G and 4G cellular networks (with speeds of 1 to 50 Mbps) and by DSL and GEO satellites (with speeds of 0.5 to 50 Mbps). Latencies with basic connectivity are greater than 50 milliseconds. Advanced connectivity can be provided with low- to mid-band 5G cellular networks (with speeds of 50 to 300 Mbps) and fiber / DOCSIS 3.x (with speeds above 100 Mbps and latency of less than 10 milliseconds). Latencies with advanced connectivity are less than 50 milliseconds. Frontier connectivity comes from high-band 5G cellular networks (with speeds above 300 Mbps and latency of less than 1 millisecond) and next-generation LEO constellations (with speeds of 50 to 200 Mbps) and fiber / DOCSIS 3.x (with speeds above 100 Mbps and latency of less than 10 milliseconds).

standard. Many (but not all) wealthier economies are moving well along this continuum, while much of the developing world is still playing catch-up.[37]

Yet connectivity is likely to take a step forward even in those parts of the world where it may not be viable to build high-band 5G networks.[38] Coverage roughly on a par with what affluent countries and major cities enjoy today will spread to more parts of the world. Adding to the momentum, prices are continuing to decline for sensors and for storage and computing capabilities (Exhibit 2).

As these developments converge, domains will gain new capabilities and more of the world will come online:

— **Enhanced broadband:** Enhanced broadband will make entertainment streaming lightning fast. Factory workers can use augmented reality glasses for quality inspections. Retailers will be able to deliver personalized promotions, augmented reality product information, and frictionless checkout using computer vision in stores.

— **Massive Internet of Things:** Low-power networks and the falling cost of sensors set the stage for the IoT to scale up like never before. It can deliver precision irrigation to crops in the field or monitor mining and drilling operations at remote sites. Dense networks of sensors embedded in the urban environment could monitor public infrastructure systems, accelerate emergency response, and improve traffic flow.

— **Mission-critical services:** Ultra-low latency and improved stability will create the confidence to run applications that demand absolute reliability and responsiveness. Some of these involve the lifeblood of a business, but others are literally matters of life and death, such as vital infrastructure systems.

— **Near-global coverage:** If LEO satellite constellations realize their potential, it will be possible for businesses to connect on a truly global scale for the first time. They can reach new consumer markets and integrate far-flung parts of the value chain. In addition, near-global coverage would enable remote environmental monitoring and disaster management. It could also greatly broaden the reach of telemedicine and digital education, beaming critical services to disadvantaged regions.

The connectivity ecosystem now has many players

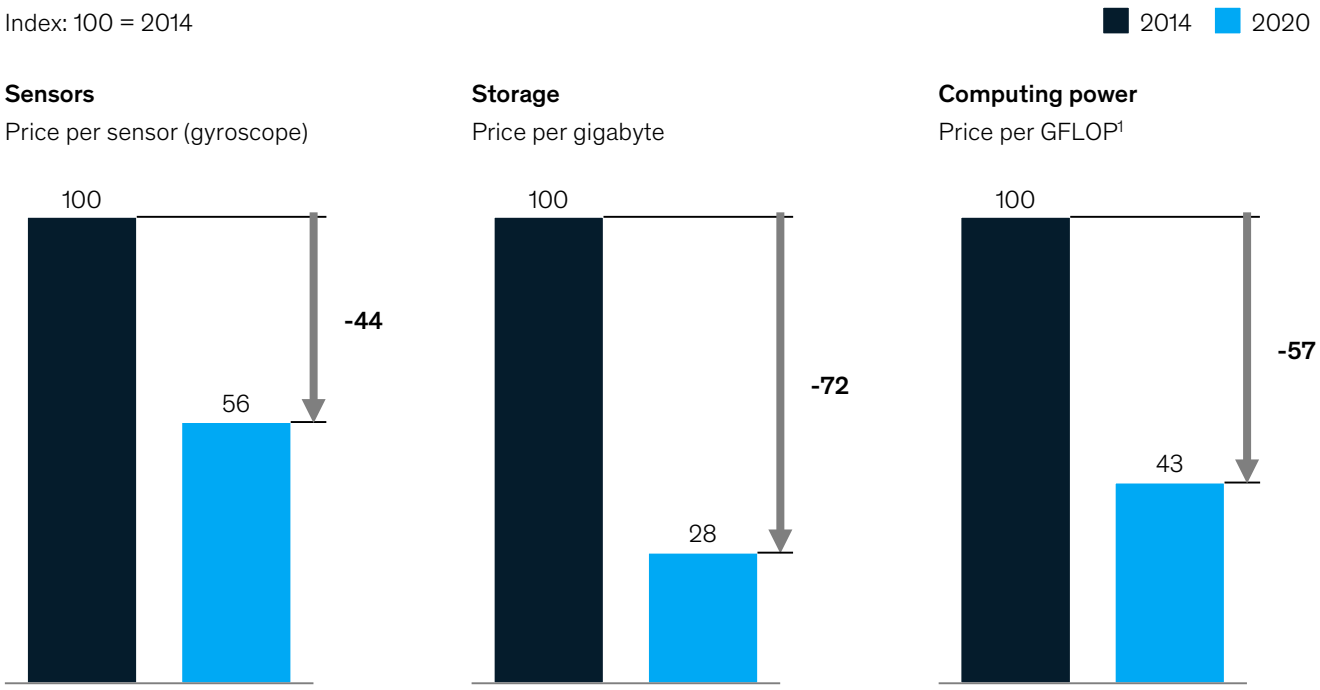
The entry of new players is reshaping the connectivity ecosystem. Some are known, while others are still emerging. While competition is ratcheting up on all sides, four of the many sources of pressure on traditional telecom companies are over-the-top streaming services, tech giants, infrastructure and tower companies, and satellites.

Connectivity providers are being challenged by new players who directly compete with their services, from cable providers to e-commerce companies. WhatsApp seized on improvements in earlier generations of connectivity to capture part of the traditional provider market. Digital giants such as Netflix and YouTube have introduced “over-the-top” services that run on the network infrastructure built by traditional telecoms—but the telecoms have largely missed out on those revenues.

[37] *The state of mobile internet connectivity*, GSMA Intelligence, 2019.
[38] Ibid.

Exhibit 2

Affordability of core technologies will make certain connectivity-driven use cases financially viable and implementable at scale.



1. Floating Point Operations Per Second.
Source: IDC, *Worldwide and US enterprise storage system forecast, 2019–2023*, May 2019; IHS, 2019; "Drastic falls in cost are powering another computer revolution," *The Economist*, September 2019; McKinsey research on commercially available GPUs; McKinsey Global Institute analysis

The portfolios of tech players and connectivity providers have begun to overlap. Tech players have introduced operator-like services (such as Apple's iMessage and Google Fi, which is an MVNO service).[39] At the same time, operators have moved into traditional tech markets such as data centers. In a world where edge computing and distribution are becoming more important parts of the value chain, the computing space will be a strategic place to capture value.

Another potential challenge for connectivity providers comes from network infrastructure providers and independent tower operators (towercos). As more companies with industrial production sites and large-scale corporate complexes see the value of having their own dedicated infrastructure, private campus networks could become an increasingly valuable piece of the connectivity market by decade's end. This could effectively cut traditional providers out of the loop. Furthermore, as towercos become bigger players, they could expand horizontally into traditional operator areas such as backhaul or small cell deployment.[40]

Conventional providers could face another challenge looming (literally) overhead, as more LEO satellite constellation companies prepare to take their services mainstream.[41] If LEO operators can overcome their technical barriers and challenges related to upfront capex and business models, they could capture a significant share of organic growth. Whether they can do so is yet uncertain (see Box 2. "Among new competitive challengers, satellites are a wild card"). Some of the fundamental issues around capital investment, risk, and revenue sources

39 A mobile virtual network operator, which is a wireless service provider that does not own the underlying infrastructure but rather leases capacity from a mobile network operator.
40 See, for example, "Towercos can capitalise on new opportunities in the dense 5G hetnet," Analysys Mason, December 2017.
41 *FCC Boosts Satellite Broadband Connectivity & Competition*, Federal Communication Commission, November 2018.

that affected the previous generation of satellite networks in the late 1990s may resurface with the new generation.

Box 2.

Among new competitive challengers, satellites are a wild card

As with all new technologies, it is still unclear if LEO offerings will gain traction and become profitable. According to US Federal Communications Commission filings, satellite density in lower orbits should triple by 2030.

One scenario would see LEO operators achieve competitive data pricing that makes their service attractive to consumers. Three developments, alone or in combination, could make this possible: venture capital funds making heavy investments and allowing for long investment cycles; social investors continuing to step in; and governments offering public support and regulatory accommodations. If LEO operators obtain sufficient support and are able to surmount their technical barriers, they could capture significant organic growth in new and low-coverage markets from conventional providers. This would also add even more capacity in an already highly supplied market, creating pricing pressure that could dampen operator revenues.

In another scenario, an oversupply of intermediate connectivity could make revenues unsustainable, particularly in combination with technical difficulties in capacity planning, transmission, and handset power requirements. If LEO operators hit all these roadblocks, they would have little to no effect on the consumer market for conventional providers. Their service would be too expensive for all but a premium niche of customers in remote areas with high connectivity needs (such as cruise ships, research stations, and remote resorts).

How all these new providers will shape market structure remains to be seen. The role governments play will also influence the connectivity markets of the future. Future spectrum costs could potentially increase capital expenditures by up to 50 percent for select operators; a wave of auctions is planned over the next few years. Further, regulatory standards will affect which players and technologies will dominate the market, and whether new business models will be viable.

2. The value at stake

Latency is measured in fractions of a second. Reliability implies the absence of disruption, delay, and frustration. Capacity is the ability to add more traffic without taking away from network performance. These metrics can seem abstract to the average person using the internet today. Yet improvements in these connectivity standards represent a building block that could enable trillions of dollars of value to be generated across the global economy.

Today consumers power the internet, with online video accounting for the vast majority of data traffic.[42] They will likely continue to drive demand growth, particularly as improved connectivity makes it possible to deliver instant downloads of ultra-high-definition movies in seconds, along with more sophisticated, immersive gaming and virtual reality experiences.

In a world where productivity growth has stalled, enhanced connectivity could open up new avenues for innovating and capturing efficiencies in every domain. Ultra-reliable, low-latency fiber and 5G networks combined with edge computing will make it possible for businesses to do more with machine learning and artificial intelligence.

We have identified hundreds of use cases across more than 17 commercial domains that can run on an enhanced digital backbone. However, in this research we examine four domains in detail (mobility, healthcare, manufacturing, and retail). Implementation of the most promising use cases we identified in these domains could increase global GDP by $1.2 trillion to $2 trillion by 2030. These use cases, discussed in Chapter 3, are meant to be illustrative rather than exhaustive, and others will likely emerge over time. Furthermore, the existence of this much value in four domains that account for roughly one-third of global GDP implies that there are opportunities worth trillions of dollars across the broader economy.

Some 70 to 80 percent of this value in the four domains can be achieved through the expansion and evolution of existing advanced connectivity technologies and networks. Frontier connectivity, which will deliver better network performance and efficiency even as data consumption continues to skyrocket, could take many existing use cases to the next level—and pave the way for entirely new ones that we cannot foresee today.

Who exactly will capture the potential value remains an open question. In some cases, it will be industry incumbents. But other use cases could give rise to new players, new alliances, and companies moving across traditional domain boundaries. That uncertainty is causing some hesitation, as we will discuss in later chapters.

Consumer use and demand for improved connectivity is driven mostly by video consumption

In the not-so-distant past, the average internet user might have logged on only sporadically to check e-mails. Today, hundreds of millions of people live a huge portion of their lives online as they text, navigate, shop, stream music, and research whatever question pops into their head.

Around the world, digital usage shows similar patterns across country categories, but those patterns are highly skewed. Some 85 percent of the world's data traffic moves through fixed networks (including Wi-Fi), although developing countries rely more heavily on cellular

[42] *Cisco Visual Networking Index: Global mobile data traffic forecast update,* Cisco, February 2019.

networks.[43] Consumers generally drive a much larger share of data demand than businesses globally and in all major regions, constituting more than 80 percent of total internet traffic on average.

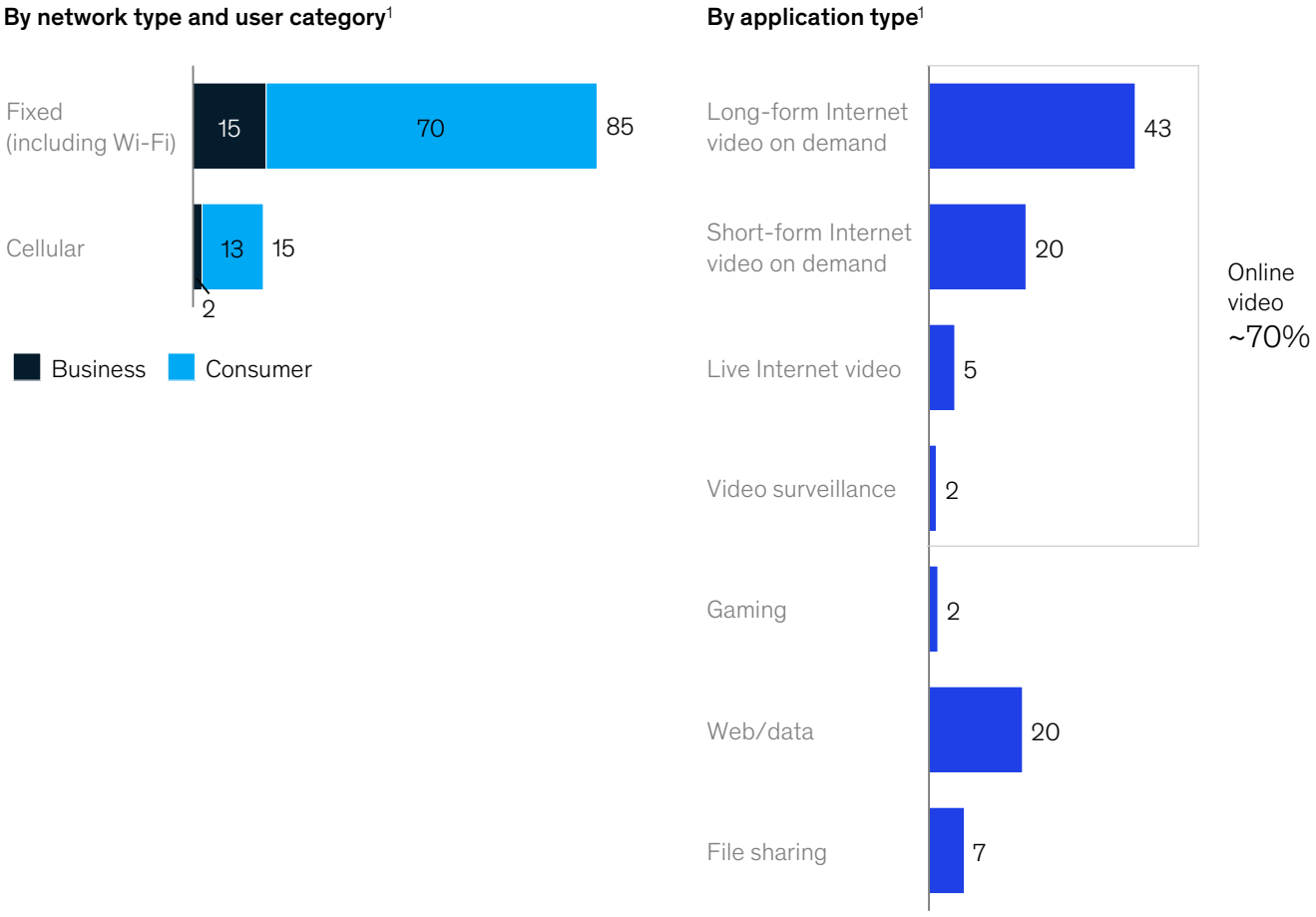
Above all, the internet is feeding an insatiable appetite for video content (Exhibit 3). From Hollywood blockbusters and streamed TV series to all manner of uploaded oddities on YouTube, video consumption accounts for some 70 percent of the world's internet traffic, with only small differences across regions and country categories.[44] While platforms, content creators, and advertising firms have benefited, connectivity providers have not been able to monetize this trend, which creates an investment challenge.[45]

Exhibit 3

Consumers generate the majority of global online data traffic, primarily for entertainment.

Global Internet data traffic

% of total Internet traffic, 2018



1. Data traffic that crosses an Internet backbone. This excludes managed IP traffic such as IP transport of TV and video on demand as well as corporate IP WAN traffic. Including managed IP traffic would keep the results highly similar as the vast majority of this kind of traffic is from consumer broadcast TV.

Source: Cisco Visual Networking Index; McKinsey Global Institute analysis

[43] Data traffic refers to traffic that crosses an Internet backbone (excluding managed IP traffic such as IP transport of TV and VoD as well as corporate IP WAN traffic). However, the results would remain similar if we include managed IP traffic, since the vast majority of this kind of traffic is from consumer broadcast TV.

[44] *Cisco Visual Networking Index: Global mobile data traffic forecast update,* Cisco, February 2019.

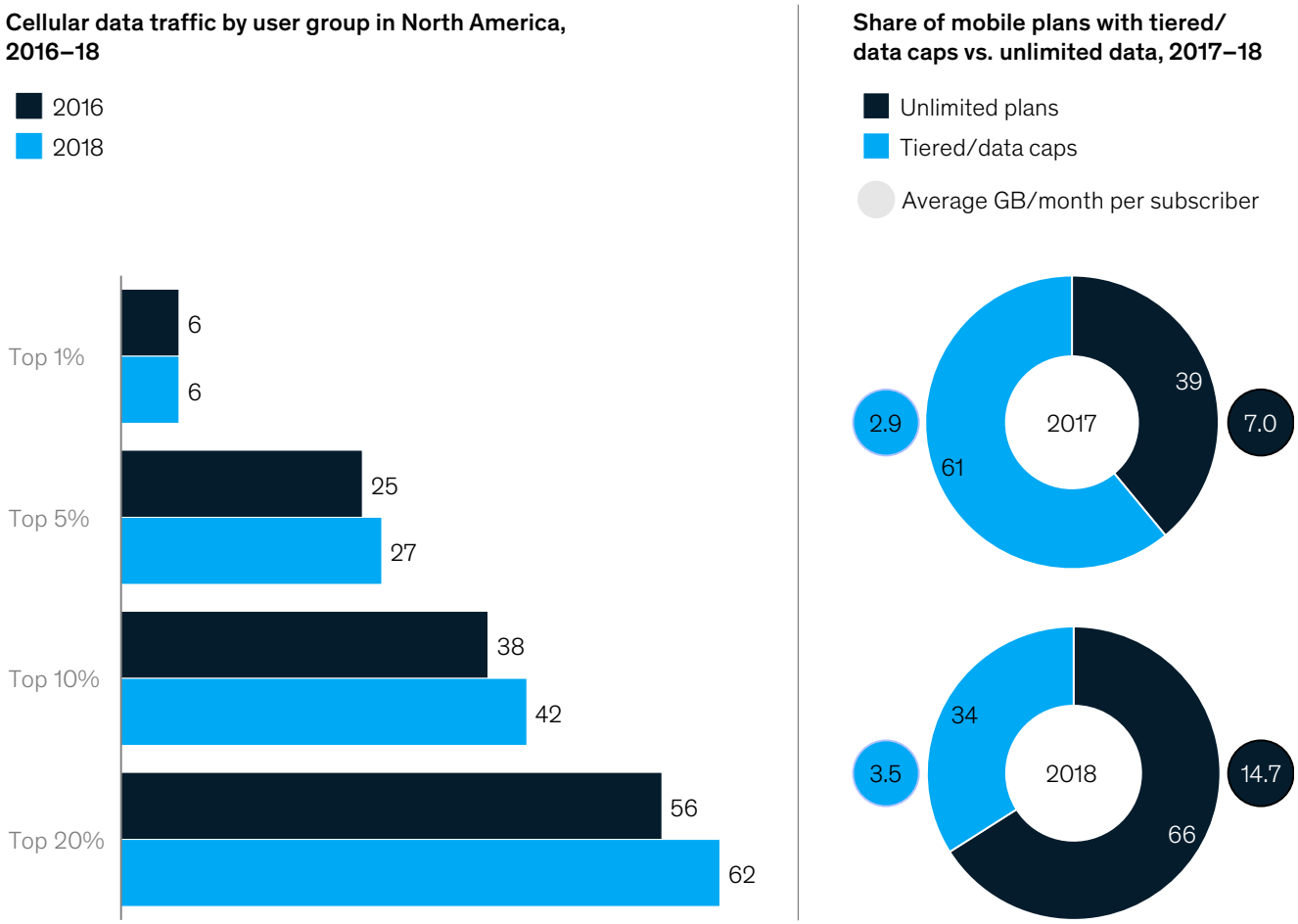
[45] See, for example, *Video as a core service for telcos: Analysis of 50 leading operators in achieving video business success,* IHS Markit and Huawei, February 2018.

Usage is also skewed at the level of individual users. A relatively small group of "power users" accounts for an outsized share of traffic on both cellular and fixed networks. In many advanced economies, the top 20 percent of users accounted for more than 60 percent of cellular data traffic in 2018. There has been widespread adoption of unlimited data plans in these markets, but nevertheless, a small group drives an unusual share of demand (Exhibit 4). In terms of fixed service, we see a similar spike at the global level: less than 5 percent of households generate more than 40 percent of global data traffic, while two-thirds of households do not use fixed internet at all.[46]

Exhibit 4

In North America, just 20 percent of users drive more than 60 percent of data demand even though most users have unlimited data plans.

% of all data plans



Note: Figures may not sum to 100% because of rounding.
Source: Cisco Visual Networking Index; McKinsey Global Institute analysis

[46] *Cisco Visual Networking Index: Global mobile data traffic forecast update,* Cisco, February 2019.

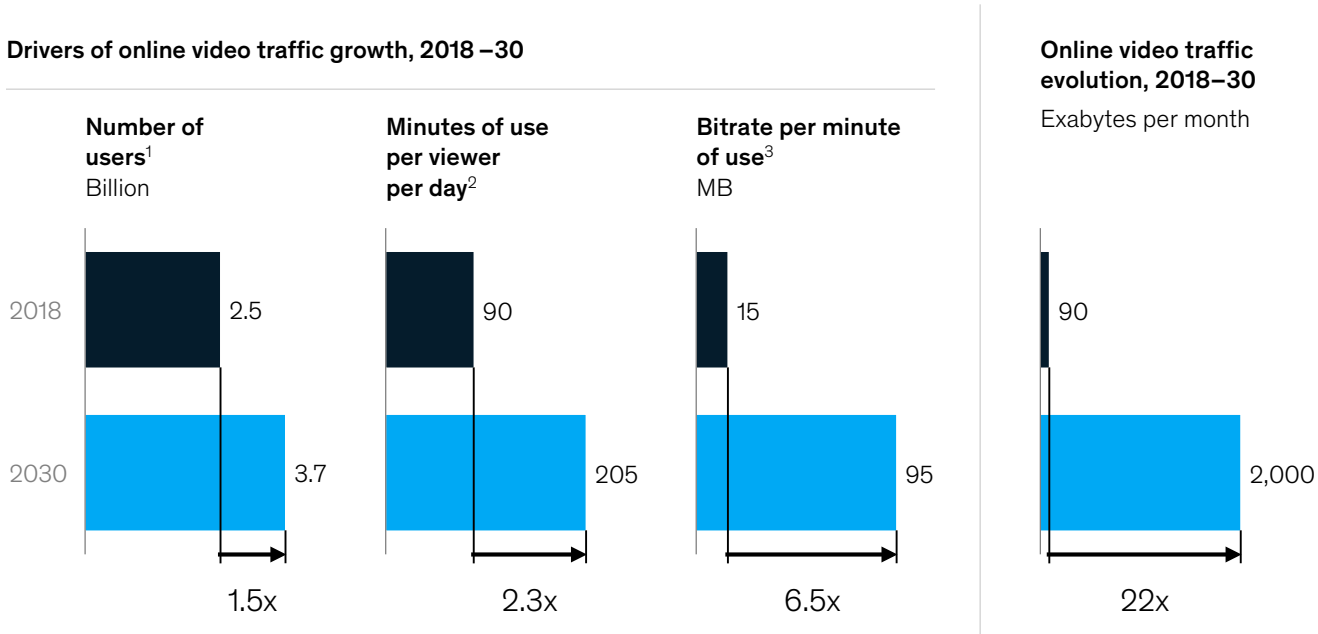
In addition to many individual commercial use cases, three key sources could drive demand for connectivity over the next decade

Three key developments may affect how the demand for connectivity and the buildout of new networks could reach equilibrium: continued growth in online video consumption, massive growth in machine-to-machine connections, and significant adoption of augmented and virtual reality.

The first development would be a continuation of existing trends, with internet traffic from online video growing 22 times larger over the next decade. The majority of this stems from the transition from today's relatively low-resolution content (SD/HD) to higher-definition content. But we also expect to see significant growth in the number of online viewers and more time spent viewing per user (Exhibit 5). New networks will have to accommodate rising demand for speed and capacity. Much of it will come from the same top 20 percent of power users who consume the majority of video content today; they are likely to be the early adopters of new connectivity technologies such as high-band 5G. New networks would be cheaper to operate due to higher spectrum efficiency—and crucially, they can accommodate a variety of services on the same infrastructure. This type of "network slicing" offers a chance to better differentiate service levels.[47] Providers could offer basic packages and entry-level pricing to regular users, who are more price-sensitive, while better monetizing the heavier consumption of power users.

Exhibit 5

Growth in the number of users and their viewing time, as well as higher-definition content, will drive massive online video traffic.



1. Most of this growth is likely to occur in India (+150%), trailing countries (+70%), and China (+45%).
2. Most of this growth stems from India and trailing countries catching up in viewing patterns as well as the ongoing shift from regular TV to online video consumption in advanced economies.
3. While low-resolution content now accounts for 95% of traffic (SD/HD), 90% of content is expected be high-resolution (UHD or 4K) by 2030.

Source: Cisco Visual Networking Index; Ovum; Sandvine; expert interviews; McKinsey Global Institute analysis

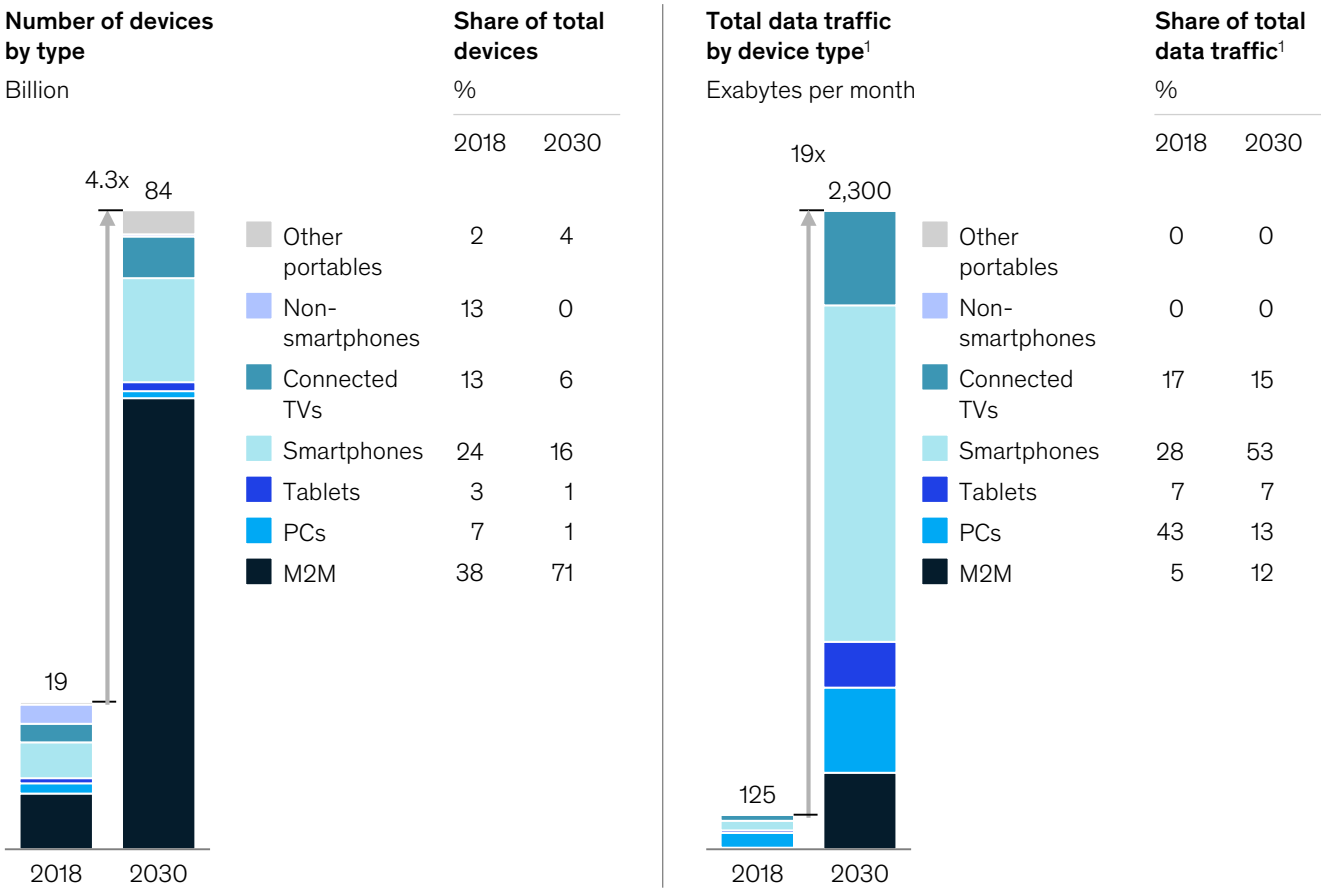
[47] Network slicing will affect cellular connected services efficiency and cost, IoT Times, July 2019

The second factor influencing the demand for connectivity and provider response is the massive increase expected in the number of machine-to-machine (M2M) connections.[48] As the Internet of Things continues to expand, it will create more smart environments in both industrial and day-to-day settings (including smart homes and smart cities), adding demand for connectivity beyond consumer entertainment and internet applications. This would require broad network coverage (likely 5G) that can reliably support very high device density with lower power consumption that can extend the life of sensors and devices. The price of sensors and hardware would also need to continue declining.[49] While M2M devices would constitute a huge majority of the world's connections, data-hungry consumer devices would likely continue as the biggest drivers of internet traffic (Exhibit 6).[50] A great deal of M2M data traffic will likely occur on private networks.[51]

Exhibit 6

By 2030, machine-to-machine devices could account for more than 70 percent of all connected devices but only 12 percent of data traffic.

2018–30



1. Data traffic that crosses an Internet backbone. This excludes managed IP traffic such as IP transport of TV and video on demand as well as corporate IP WAN traffic. Including managed IP traffic would keep the results highly similar as the vast majority of this kind of traffic is from consumer broadcast TV.

Note: Figures may not sum to 100% because of rounding.

Source: Cisco Visual Networking Index; McKinsey Global Institute analysis

48 *Cisco Visual Networking Index: Global mobile data traffic forecast update,* Cisco, February 2019

49 Mansoor Shafi et al., "5G: A tutorial overview of standards, trials, challenges, deployment, and practice," *IEEE Journal on Selected Areas in Communications*, volume 35, issue 6, June 2017.

50 We define Internet traffic as crossing an Internet backbone, which excludes managed IP traffic such as IP transport of TV and video on demand as well as corporate IP WAN traffic.

51 *Cisco Visual Networking Index: Global mobile data traffic forecast update,* Cisco, February 2019

A third factor, less certain than the two trends described above, is the possibility that augmented and virtual reality applications could take off with consumers. Since they would have to be enticed to upgrade their devices and service levels, this scenario is more hypothetical. It depends on whether a critical mass of people find augmented and virtual reality entertainment compelling. Headsets and hardware would also need to improve from today's quality and drop in price. These technologies require connectivity with high capacity, reliability, and extremely low latency.[52] Delivering it would require providers to make heavier investments in enhanced broadband, 5G, and edge computing.

Use cases in four domains could boost global GDP by up to $2 trillion, mostly running on advanced connectivity

As connectivity improves over the next decade, new commercial capabilities are emerging. Hundreds of potential domain use cases could change the way businesses operate.[53] On the world's new digital backbone, companies will be able to do more—and do it on a bigger scale, improving their own performance and creating broader economic impact. Based on extensive research and expert interviews, we have identified hundreds of domain use cases running on both advanced and frontier networks, independent of the many consumer-driven entertainment and internet applications that are possible. To illustrate the sheer diversity of possible use cases, as well as some of the opportunities and implementation challenges, we profile four commercial domains with large potential to capture higher revenues or cost efficiencies.[54]

Broadly speaking, the use cases identified in these four domains fall into one of two categories. Approximately 55 to 65 percent of them deliver productivity and efficiency improvements, while some 35 to 45 percent are focused on topline growth and innovation. Within these categories, use cases are further segmented based on the way in which they create value. In the case of productivity and efficiency, they may improve labor, asset, or resource productivity. Those focused on topline growth and innovation may expand existing revenue streams or create new ones (Exhibit 7). Chapter 3 takes an in-depth look at how companies in mobility, healthcare, manufacturing, and retail could take advantage of some of the use cases that are enabled by advanced connectivity.

The specific use cases that we sized across these four commercial domains alone could boost global GDP by an estimated $1.2 trillion to $2 trillion by 2030. This is equivalent to 3.5 to 5.5 percent of their expected GDP. However, others could exist today or emerge in the future in these domains, which would increase the economic impact.

The types of use cases we sized in these four areas are relevant in other domains as well.[55] Next-generation inventory management, for example, has applicability beyond retail; it also has value for logistics and consumer goods companies. Improving equipment utilization applies not only in factories but also in mining, oil and gas, and commercial real estate operations. Over and above the value generated in mobility, healthcare, manufacturing, and retail (which collectively account for a third of global GDP), use cases running on advanced and frontier connectivity could generate trillions of dollars in value across the entire global economy.

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52 *Cloud AR/VR Whitepaper*, GSMA Intelligence, April 2019.

53 We use the term "domain use cases," recognizing that some will involve industries and ecosystems that cross traditional industry lines. This term also applies to applications driven by industries that are ultimately consumer facing, such as retail and healthcare.

54 In addition to illustrating the range of use cases, these domains were chosen as a large, representative cross-section of the economy. They include both industrial and consumer-facing businesses, with a diverse mix of assets, occupations and geographic footprints, and they span many different supply chains.

55 On 5G specifically, several papers make the point that the economic potential is linked to business use cases and cross-industry relevance. See for instance "The road to 5G networks: Experience to date and future developments," OECD Digital Economy Papers, No. 284, July 2019; also "The 5G economy: How 5G technology will contribute to the global economy," IHS Economics and IHS Technology, January 2017.

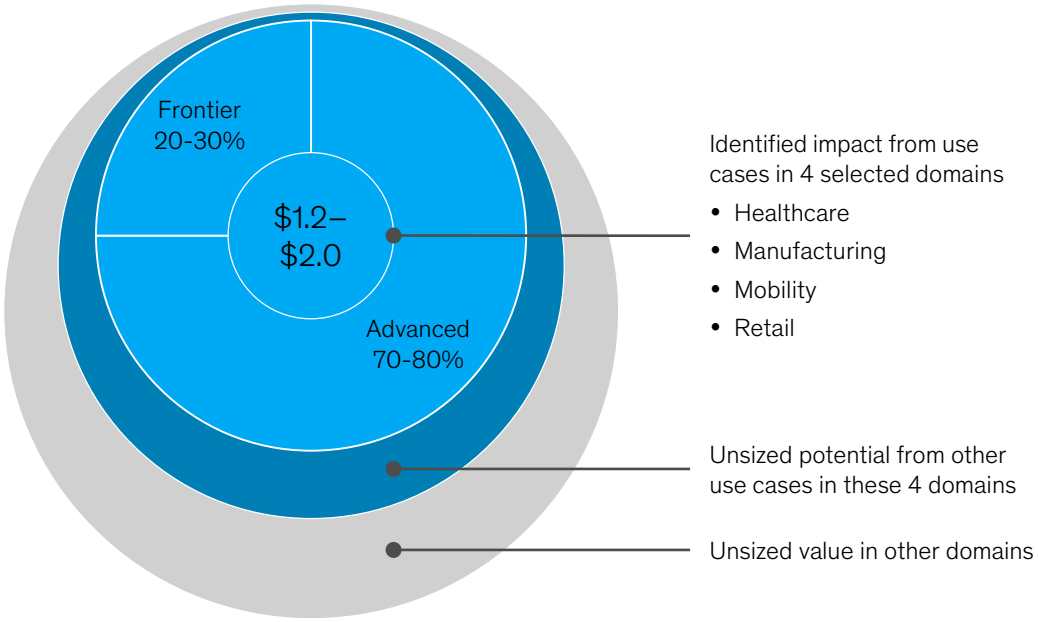
Exhibit 7

We analyzed use cases across four domains.

Connectivity will unlock value in these domains and beyond

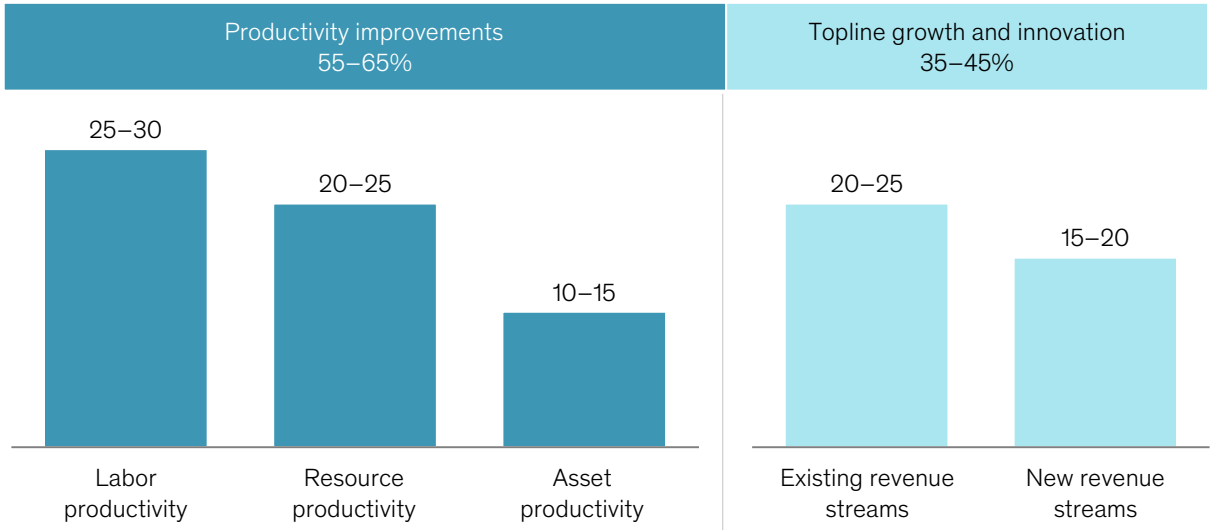
Projected GDP impact from enhanced connectivity, 2030

%; $ trillion



Breakdown of impact category on selected use cases (healthcare, manufacturing, mobility, and retail)

% of total use cases selected



	Labor productivity	Resource productivity	Asset productivity	Existing revenue streams	New revenue streams
Example use cases	Tools to improve product and service quality, enhance prioritization of customers and tasks, and reach a larger customer base	Increase operational and process efficiency and output by better managing waste, reducing product spoilage and shrinkage	Remote monitoring of sites, preventive equipment maintenance, better inventory tracking	Enhancing product features, taking existing offerings to new settings and to larger markets	New products using AR/VR, machine-to-machine services

Note: Figures may not sum to 100% because of rounding.
Source: McKinsey Global Institute analysis

There are additional economic benefits to businesses, consumers and society that are not captured in this analysis. They include, for instance, the ability for businesses to differentiate themselves by creating a rich customer experience; the benefit of having better health outcomes and healthier, more productive citizens; and the ability to reduce waste and better manage capital and natural resources in production processes.

In the four domains we studied, advanced connectivity can enable some 70 to 80 percent of the economic potential. A great deal of room can be achieved without investing in frontier connectivity. This is because even in the wealthiest economies, only a relatively limited set

of leading companies are deploying the most ambitious use cases that can run on today's networks. As connectivity, technology tools, and services become more affordable and mainstream, there is much more room for adoption to spread across domains, driving bigger productivity gains. Declining prices for RFID and NFC tags, for example, could mean they can be used on many more consumer goods, which may magnify the benefits of automated inventory management systems for retailers.

By contrast, use cases that require frontier connectivity such as high-band 5G could eventually generate some 30 percent of the potential impact. High-band 5G will create greater network efficiency, boosting speeds even as providers accommodate more consumer demand and more devices. Existing use cases can run on a bigger scale while becoming more sophisticated and reliable. Tens of thousands of infrastructure sensors in a dense urban area could capture real-time data, sending alerts to vehicles and public agencies securely in real time to manage traffic and speed emergency response. Frontier connectivity can also analyze enormous quantities of video from networks of camera installations. However, while this has important applications in law enforcement and security, it also raises concerns about privacy and misuse that need to be addressed with safeguards.

For many users, a key selling point of high-band 5G is lower latency. Manufacturers, in particular, are gravitating toward these networks to implement system-wide real-time process control across multiple lines and plants. Ultra-low latency is also important for augmented reality entertainment as well as AR tools for quality inspections and worker training.

It is possible that the value of use cases running on frontier connectivity could exceed our estimates, depending on whether some high-potential but still speculative use cases like augmented reality and self-driving vehicles fully come to fruition. A stronger digital backbone can also support new use cases we cannot predict today. The extent to which these developments—and the related demand—actually materialize will likely have a meaningful impact on the deployment and adoption of frontier connectivity.

Beyond the business value is an opportunity to bring more people online, enabling up to $2 trillion in GDP impact

Despite broad global adoption of mobile connectivity, nearly 40 percent of the world's population remains offline altogether or under-connected (that is, they are not yet using 3G-capable data networks or better). There is great human and economic potential in bringing them online, including improved communication, social inclusion, and enhanced productivity across domains.[56] Connectivity can, for example, create a platform for bringing mobile finance to previously unbanked populations and expanding access to credit in developing countries.[57] The internet could be a great equalizer. In fact, providing "universal

[56] The World Bank's literature review of multiple cross-country and single-country studies finds a positive economic impact from the expansion of fixed broadband and mobile coverage. See Michael Minges, *Exploring the relationship between broadband and economic growth,* January 2015. For more on the channels through which digital inclusion spurs economic growth, see *World development report 2016: Digital dividends,* World Bank Group, 2016.

[57] For more on this topic, see *Digital finance for all: Powering inclusive growth in emerging economies,* McKinsey Global Institute, September 2016.

and affordable access to the internet in the least developed countries" is one of the UN's Sustainable Development Goals.

By decade's end, the share of the world's population remaining under- or unconnected could decrease by half. This is due to a mix of organic factors driving adoption (such as rising incomes and literacy rates) plus the expansion of network coverage and the overall increasing affordability of devices and services. This newly online population will likely gain intermediate connectivity via 3G or 4G/LTE cellular networks.[58]

In real terms, this means that they will be able to enjoy basic web browsing, consumer mobile phone applications, e-commerce, and the consumption of online video. This stands in contrast with users of advanced and frontier mobile connectivity, who will be able to stream ultra-high-definition video, participate in ultra-low-latency high-definition cloud gaming, enjoy immersive virtual and augmented reality applications, and have first access to other consumer applications that have yet to be defined. But new users in the developing world will gain access to critically important capabilities and services, from news and information to mobile financial services.

Bringing more of the world online could add some $1.5 trillion to $2 trillion to global GDP by 2030. Beyond the clear social and economic benefits, this growth in mobile subscribers would be a significant boon to connectivity providers—at a time when they sorely need new sources of revenue. See Chapter 5 for more on this topic.

[58] We use the term "intermediate connectivity" to refer to access to 3G and 4G/LTE cellular networks (with speeds of 1 to 50 Mbps and latency of ~50 milliseconds or more). Compared to advanced and frontier connectivity that we defined previously, intermediate connectivity features different technical capabilities, supported applications, and subscriber populations.

3. Connectivity at work: Use cases in select domains

Both advanced and frontier connectivity will provide companies of all kinds with a platform for applications that can boost efficiency and innovation. The range of new use cases that can run on top of a stronger digital backbone is remarkably broad—and it may eventually include some that we cannot imagine today.

As noted in Chapter 2, we have identified hundreds of potential use cases across 17 domains of the global economy ranging from agriculture and industrials to healthcare and education.

To illustrate the diversity of what is possible and the economic opportunity, we highlight four of these domains with significant potential to capture higher revenues or cost efficiencies. This chapter takes a deeper look at select use cases that could materialize in mobility, healthcare, manufacturing, and retail. In these domains alone, some $1.2 trillion to $2 trillion of GDP value is at stake—along with the possibility of enhancing health and safety as well as making industrial operations more sustainable. The use cases described in the chapter are meant to be illustrative rather than exhaustive, and others will likely emerge. We also consider scenarios for how the domains themselves could evolve as use cases are adopted. Finally, we consider some of the challenges that need to be addressed to scale up adoption in each domain.

Connectivity underpins major changes unfolding in mobility and automotive

Cars are already getting smarter. Their systems provide enhanced safety; navigation; maintenance alerts; and voice control of music, phone calls, and messaging.

Incremental feature upgrades in traditional vehicles are only part of the story. In cities worldwide, e-hailing and other digitally powered shared transportation services have transformed the way people get from point A to point B. Rides can be hailed by tapping an app. Electric vehicles are making inroads, and they could take off sharply as battery prices continue to fall and recharging infrastructure is built out. The concept of "mobility" itself reflects the broadening of options for getting around and the formation of an ecosystem. In addition to automakers, this ecosystem includes car-sharing services, public transit, infrastructure, hardware and software, and more—in short, all of the actors and enablers involving in moving people (and goods) from point-to-point on the ground.

The decade ahead promises even bigger shifts. Optimizing the utilization of vehicles and infrastructure and expanding shared mobility solutions will be paramount in crowded cities. The market for vehicles with advanced driver assistance systems should continue to grow by 15 percent a year in Europe and almost 30 percent a year in China.[59] Below we focus on the use cases and dynamics emerging exclusively from advanced and frontier connectivity.

[59] This refers to vehicles with up to Level 3 autonomy, as defined by SAE International. See "SAE International releases updated visual chart for its 'Levels of Driving Automation' standard for self-driving vehicles," SAE International, December 2018.

Use cases and the value at stake

Technologies such as low- to mid-band 5G, sensors, and short-range communication systems enable cars to interact seamlessly and continuously with the world around them. This new type of "vehicle-to-everything" communication has four dimensions, with each one supporting multiple use cases and new sources of value.

Vehicle-to-network communication: V2N provides high bandwidth, low latency, and increasingly broad coverage. This will allow cars to add new capabilities such as real-time monitoring of the driver's health condition and instant over-the-air software updates. In addition to streaming video for passengers, advanced connectivity could even deliver a full haptic/4D video or gaming experience that integrates the twists and turns of the road.[60] We estimate that multiple types of personalized "infotainment" could create some $15 billion to $20 billion in revenue opportunities in subscription services alone. In addition, networks that support video conferencing could turn cars into "rolling offices," allowing passengers to be more productive. Advanced connectivity also makes it possible to take a more predictive and proactive approach to vehicle maintenance. Manufacturers can monitor the condition of each system in the car through signals sent by IoT sensors and notify the owner to schedule repairs before a breakdown occurs, improving the vehicle's durability and lifespan. Service offerings could even include unsupervised towing, repairs, and returns so that no time and energy is required of owners. Predictive maintenance represents a potential new revenue pool of $45 billion to $70 billion annually.

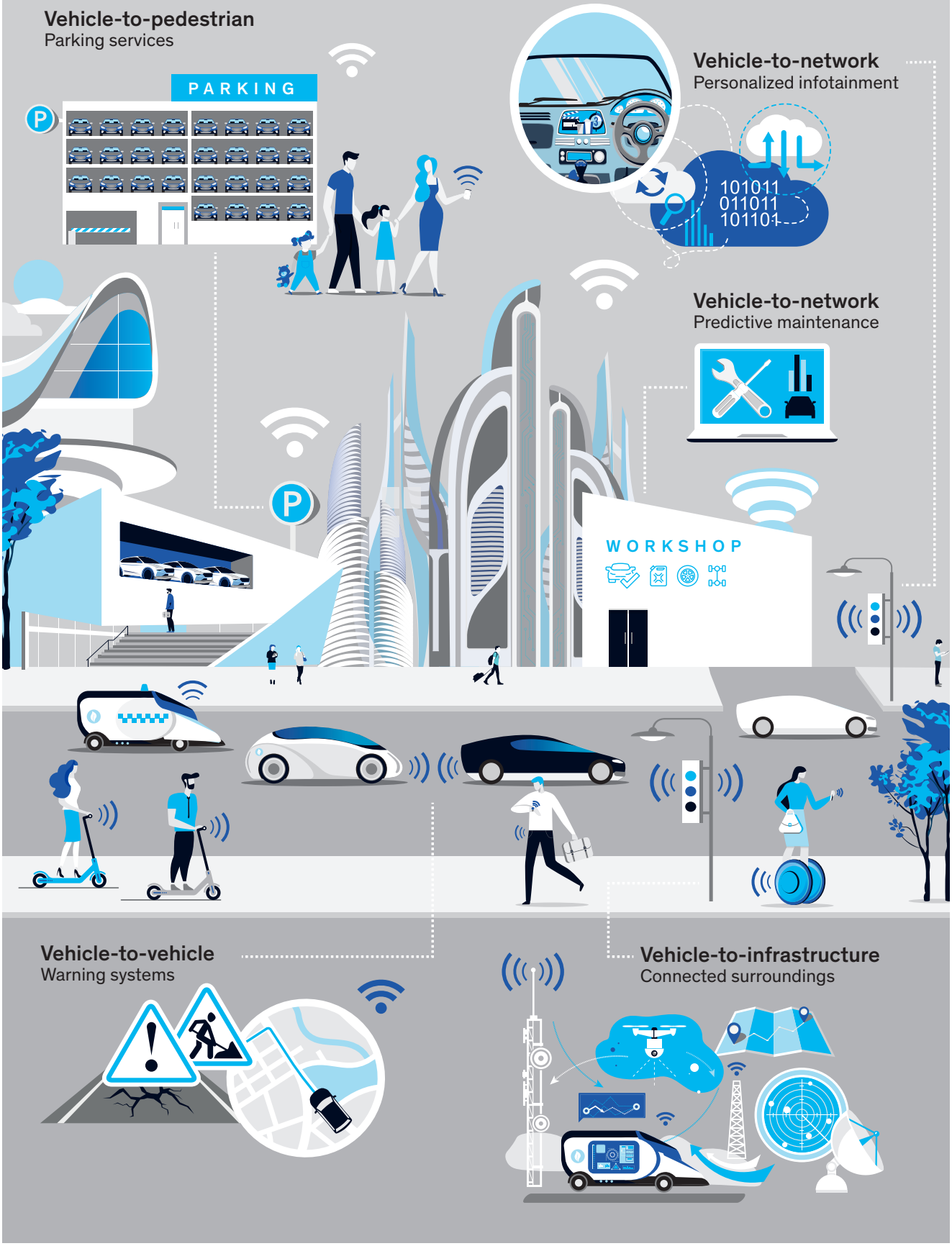
Vehicle-to-vehicle communication: V2V technology relies on short-range connectivity. It involves cars "talking" to each other and driving cooperatively—a breakthrough that can improve the flow of traffic, avoid collisions, and pave the way for autonomous and semi-autonomous driving (see Box 3, "Connectivity and autonomous vehicles"). Vehicles can drive together more closely with shorter distances between them at highway speeds. In addition to lessening congestion and improving fuel economy, this would increase the capacity of existing roads, lessening the need for costly new builds. Vehicles that encounter hazards such as potholes, ice patches, or debris can give others advance warning. We estimate that warning systems can lower the cost of vehicle repairs by $20 billion to $30 billion annually—not to mention the lives that can be saved and the injuries that can be prevented.

Vehicle-to-infrastructure communication: V2I, running on low- to mid-band 5G as well as short-range connectivity, enables two-way signals between vehicles and roads, traffic lights, bridges, toll collection points, and other infrastructure. This could help drivers and passengers optimize their routes, cutting down on time lost in traffic. It would also give public agencies more sophisticated tools for real-time traffic management and valuable data on road usage, public safety, and maintenance needs for future planning. Overall, we estimate that some $10 billion to $15 billion in cost savings and revenue opportunities could be realized from improved navigation systems and navigation subscription services. On top of this comes the countless hours saved and reduced city smog from better traffic planning.

Vehicle-to-pedestrian communication: Utilizing low- to mid-band 5G and LPWA networks, V2P connects vehicles with smartphones and other devices held by people on the street (and with the broader environment, such as gas stations). This should improve safety by ensuring that cars react to avoid hitting pedestrians. Along with the safety element, V2P can give pedestrians an integrated view of the fastest and most comfortable way to reach their destination. We estimate that additional services such as offering parked cars to pedestrians as pick-up spots for packages, carpooling, or subscription services for automatic refueling could potentially be worth some $5 billion to $10 billion annually.

[60] "Setting the framework for car connectivity and user experience," McKinsey.com, October 2018.

In the connected mobility system of the future, vehicles communicate with the world around them.



Box 3.

Connectivity and autonomous vehicles

By definition, the truly autonomous vehicles of the future will not rely on a permanent network connection to navigate busy city streets without human intervention. However, enhanced connectivity such as 5G can accelerate the development and commercial roll-out of autonomous vehicles.

In current connected cars and pilot autonomous vehicles, a significant amount of data processing from sensors and lidar systems is done within the vehicle itself, using costly supercomputer hardware. In the future, however, new roads and infrastructure with reliable ultra-high-speed, low-latency connectivity (such as high-band 5G) could possibly transfer these tasks to the edge or the cloud, decreasing hardware costs. Furthermore, various V2X communications could be supplemented with high-band 5G connectivity with low latency for rapid and secure data transfer. Lastly, these frontier connections will enable live software updates and data refreshes (such as live layer maps) through over-the-air updates.

In sum, although we do not consider "autonomous driving" as a separate use case in our sizing, these capabilities will create meaningful value to enterprises, consumers, and society by progressively steering toward a future of full autonomy.

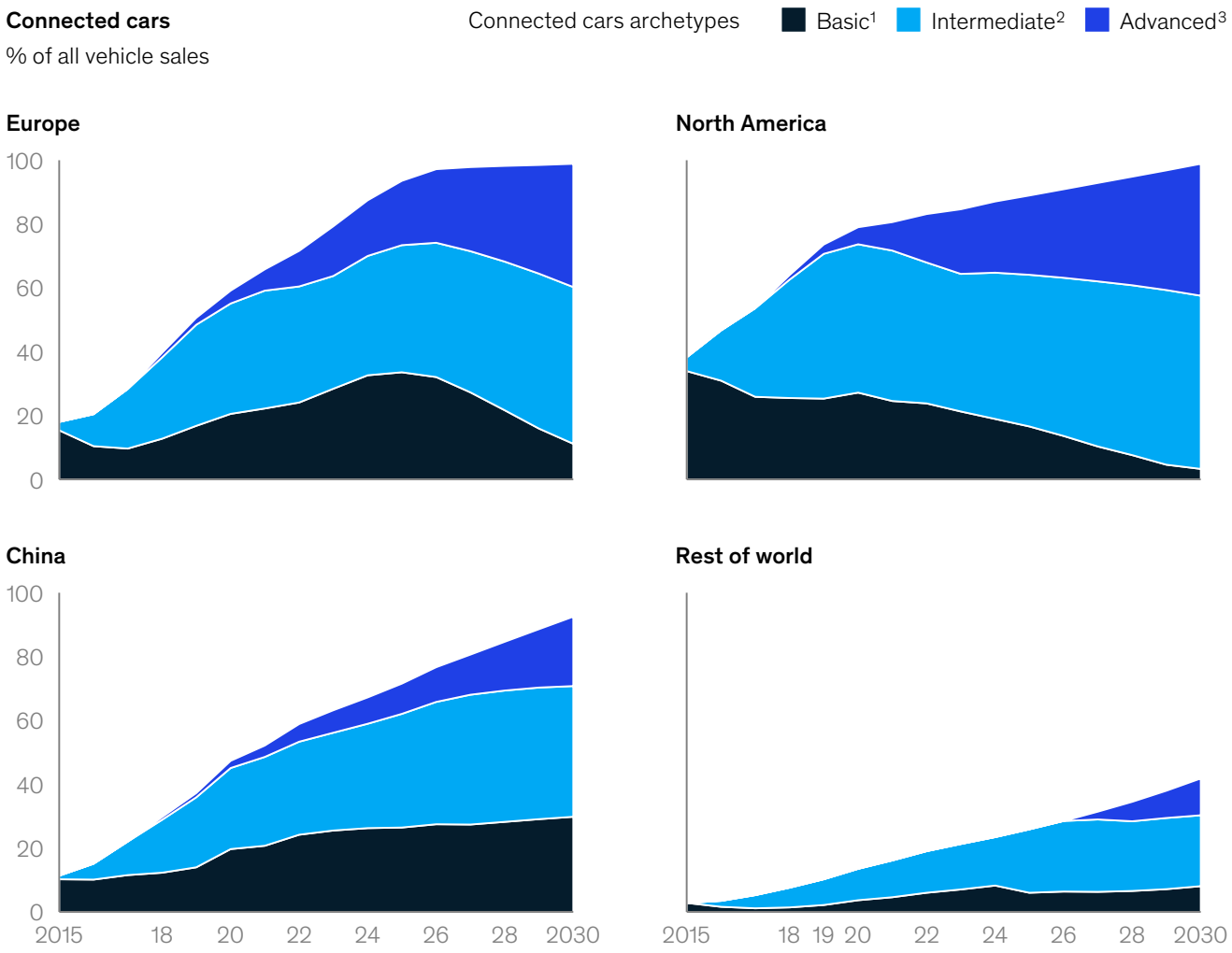
The use cases described above are only a few examples of how connectivity on roadways and in vehicles could open up new revenue streams and create cost savings. All told, we find that improved connectivity could enable more than 80 other innovations in mobility.

Looking at the penetration rates of connected vehicles in different regions, we find significant variances in adoption, due to infrastructure differences, regulation, and other factors (Exhibit 8). We then extrapolated the individual car unit prices and adoption rates of use cases to the overall pool of vehicles in operation.

In total, we estimate that mobility use cases could generate $170 billion to $280 billion of GDP impact by 2030.

Exhibit 8

The penetration of connected cars will continue to rise.



1. General hardware connectivity; car-enhancing basic features such as guided navigation, driving statistics.
2. Preference-based personalization; car-enhancing intermediate features such as personalization of services, accessible directly from the dashboard.
3. Intelligent system; car-enhancing advanced features such as multisensorial live interaction and unsupervised intelligence.

Source: McKinsey Center for Future Mobility; McKinsey Global Institute analysis

Implications for the mobility ecosystem

The traditional automotive value chain has evolved considerably in recent years, and it will continue to morph as mobility moves toward a more connected future of electric, shared, and autonomous vehicles (Exhibit 9). The race to be in the forefront of this fast-changing market has already given rise to dozens of strategic partnerships between automakers, tech companies, and new players along the value chain. The roles played by providers of network infrastructure, operating systems, and cloud platforms as well as app developers and distributors will continue to expand.

However, it is not fully clear how the mobility ecosystem will look in a decade's time. Three scenarios could unfold (Exhibit 10). One possibility is that automakers and their suppliers form platform alliances to share R&D and deployment costs and retain ownership of a common operating system and data platform. This would benefit traditional manufacturers, connectivity providers, and the app and service providers that manage to partner in development. However, automakers would need the relevant expertise and capabilities to compete with established tech firms.

Exhibit 9

The connected mobility ecosystem will include new types of services and players.

	Connectivity infrastructure	Backbone for the entire system; may include 5G, LEO satellites, etc
	Connectivity providers	Data services to enable communication from vehicles to networks and other service providers
	OEMs and parts suppliers	The vehicles themselves, including the software, sensors, and platforms they need to integrate into the environment
	Operating systems	In-vehicle computer operating systems
	Cloud platforms	Some in-vehicle data processing could eventually be transferred to the cloud
	App services	Application software and add-on features for consumers, such as fleet management, mapping services, and voice recognition
	App stores	Marketplace/consumer front end for drivers and passengers to access new features and products
	Aftermarket suppliers	Maintenance and service, including critical replacements and upgrades of connectivity hardware and software components

Source: McKinsey Center for Future Mobility; McKinsey Global Institute analysis

Another plausible scenario would see a major tech player or a group of tech players dominating the market for operating systems and cloud services for vehicles. This would allow automakers to keep their focus on vehicle development, licensing customized versions of the standard operating system to suit each model. This scenario could occur if a major tech player manages to build on its established consumer base in other domains to reach a critical mass of adopters quickly. Still another possible path would see multiple tech players competing with their own functional platforms, with a smaller ecosystem revolving around each one.

Both traditional automotive and parts manufacturers and tech players should regard mobility as a broad and complex ecosystem that no single player can fully control. Mobile phones, for example, moved away from individual companies developing propriety hardware and operating systems to open operating systems that can be adapted to local needs, inviting third-party app development and monetization. Automakers can consider a similar approach by opening up their platforms and hardware, looking to app developers and other partners with complementary capabilities to provide services.

Exhibit 10

Three scenarios are likely for the connected mobility ecosystem.

Dominating player in ecosystem Partnership with dominating player

Value chain	Platform alliance	Platform monopoly	Platform oligopoly
Connectivity and infra-structure	Infrastructure players	Tech player infrastructure	Infrastructure players
		Other infrastructure players	Infrastructure players
Connectivity providers	Telecom players in alliance with OEMs	Telecom players	Telecom players
	Other telecoms		Telecom players
OEMs and parts suppliers	OEMs	OEMs	Platform player parts supply
	OEMs		OEMs
Operating systems	OEMs, telecoms, and other alliance platforms	Single major platform player	Platform players
Cloud platforms	Cloud providers		Cloud providers
App services	Smaller app providers	Integrated app services	Smaller app providers
		Smaller app providers	
App stores	OEM app stores	Platform player app store	Platform player app store
	Other OEM app stores		
After-market suppliers	OEM services	Platform player workshops	Platform player workshops
	3rd-party suppliers		
Main region in scope	Europe	North America	China
Likelihood of materializing	Medium	Very high	High

Source: McKinsey Center for Future Mobility; McKinsey Global Institute analysis

Connectivity providers will want to avoid being regarded as providers of a commoditized service in this ecosystem and become credible partners, perhaps in the development of specific features and services. Each player's position will be affected by which operating systems and features attract a critical mass of users, their own ability to integrate with other platforms, and whether they have deep capabilities to compete in multiple areas. There is a unique opportunity for the companies that recognize the possibility of actively taking part in shaping the dynamics of their local mobility ecosystem.

Some issues to be addressed

Automakers, suppliers, technology and infrastructure players, service providers, and dealers alike have yet to capture the full value of connectivity, whether in revenue, safety, and operational efficiencies. A few specific challenges stand out.

Scaling up connectivity services requires skills and resources that stretch beyond any single player. To span this gap, collaboration will be key. In a recent McKinsey survey, executives overwhelmingly identified automakers as harder to partner with than start-ups or tech players.[61] Nonetheless, monetizing car data will require real digital ecosystems along the value chain.

Today the current "connected service" strategy is not always rooted in a clear vision of what the end customer wants or needs; it has been changing incrementally on the basis of hardware and software advances.

In addition to understanding how these features might make their lives easier, customers must trust that the data they share will be held and used responsibly. For most of these applications, data gathering could be affected by new individual consent requirements introduced by regulations like Europe's GDPR.[62] Automakers are approaching this differently. Some are adopting an opt-in approach that obtains an individual's express consent before collecting personal information. The opt-out approach used by other automakers requires consumers to proactively decline personal data tracking and storage. Customers will only opt in if they are convinced that the exchange—whether via advertising or a direct fee—is worthwhile relative to the feature's value.

Development of new connected services will require companies to take a different organizational approach. They will need to shift away from rigid, siloed operations, although the McKinsey executive survey revealed that most companies do not have a clear view of what the ideal structure could be.

Lastly, more enhanced connectivity service experiences will require continuous coverage of high-bandwidth, low-latency network like 5G over relatively large areas. Currently, there is limited visibility on actual future investment to support this outside of urban pockets. Similarly, while V2X pilots are underway, meaningful adoption of these use cases would need broad adoption across the entire car parc (all cars on the road), not just new sales. Even if all new cars are fully connected, it will take years for the entire car parc to turn over.

61 "Accelerating the car data monetization journey," McKinsey.com, March 2018.
62 The General Data Protection Regulation.

Connectivity could unlock elusive productivity gains in healthcare, bending the cost curve and improving the quality of care

Patient histories have gone from paper to electronic medical records. Data is increasingly being aggregated to develop new treatments and identify the most effective protocols. Solutions such as telemedicine are making consultations more convenient in advanced economies—and bringing much-needed medical care to regions with limited access.[63]

Despite this, technology has not delivered the kind of progress that many expected. Compared to other domains, healthcare has lagged in digitizing.[64] Furthermore, the value created by technology-enabled services is hard to isolate. Many of the benefits diffuse across health systems. In some cases, they have led to growing demand, not all of which is related to need. Along with patients requiring treatment, the "worried well" are also finding it easier to access care.

Powerful tools such as advanced analytics, AI-powered diagnostics and population health analytics, connected medical devices, and wearables all depend on enhanced connectivity. However, realizing the full potential these technologies can deliver will require far more substantial changes in how health systems operate, enablers and incentives, and the players within the ecosystem.

Use cases and the value at stake

Under the right circumstances, improved connectivity could help to reduce costs by delivering productivity improvements and better outcomes and free up investment capacity that will most likely go elsewhere in the domain. We estimate that enhanced connectivity could enable efficiency gains that would translate into $250 billion to $420 billion of GDP impact by 2030. We estimate that advanced connectivity can deliver about 80 percent of the value at stake, while frontier connectivity accounts for the remainder.

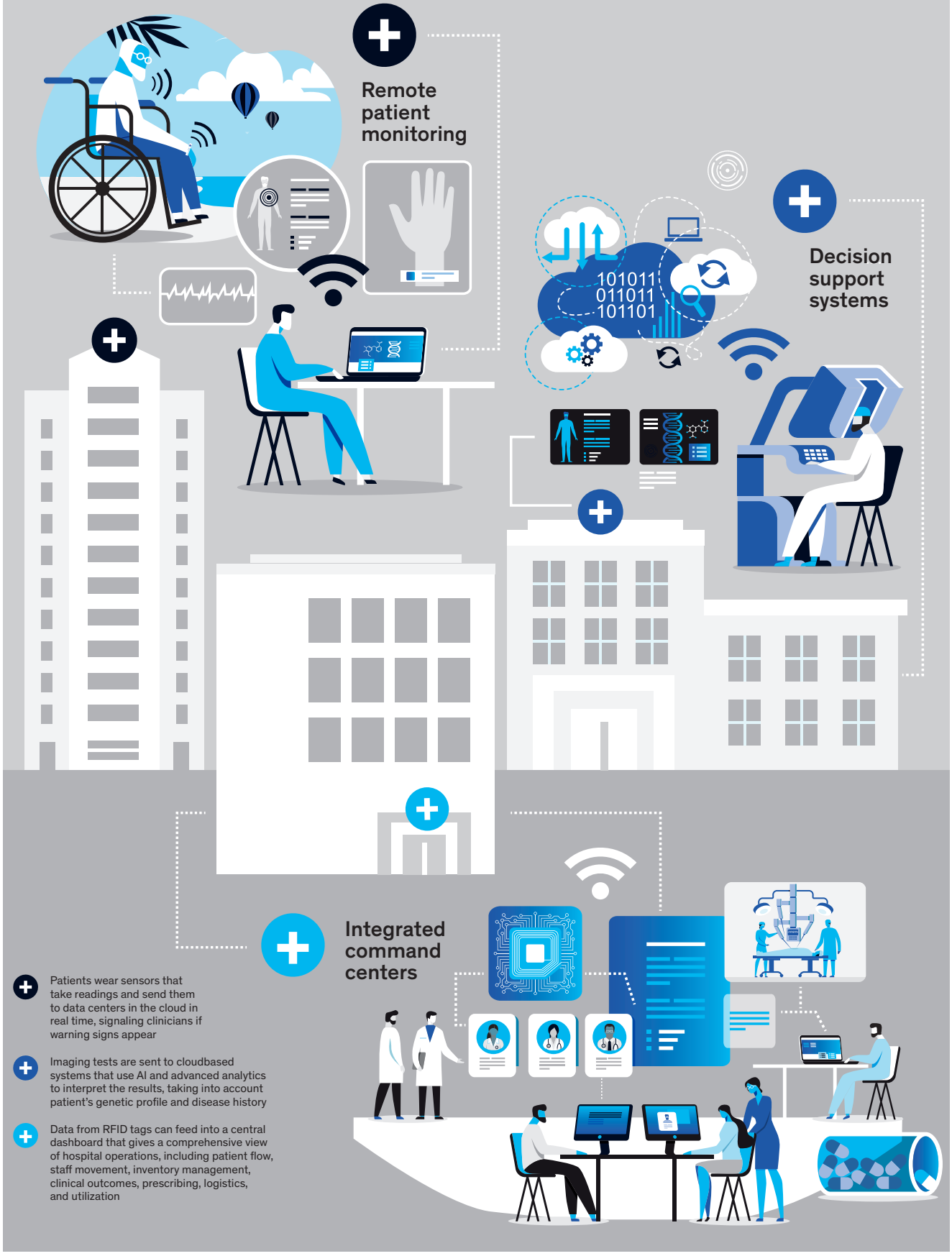
Realizing the benefits of enhanced connectivity is one part of a multi-step journey. The overall benefits of digitizing healthcare (beyond connectivity-related benefits) are massive and could unlock some $1.5 trillion to $3.0 trillion annually by 2030.[65] This would represent efficiencies of 11 to 20 percent of the nearly $15 trillion in global healthcare spending MGI projects for that year. Beyond these direct economic benefits, a further digitized healthcare system could also have significant indirect effects on the economy resulting from better health outcomes and healthier populations. We estimate that this effect could further boost global GDP by some $2.1 trillion annually.

A few use cases serve to highlight the potential impact of connectivity in healthcare:

Remote patient monitoring: Wherever they are, patients with wearable sensor devices on or underneath the skin can have frequent checks of vital readings such as heart rate, blood pressure, glucose level, and oxygen saturation. The resulting data can be instantly transmitted on an advanced mobile connection for evaluation. These systems can signal both patients and care providers in real time if preventive measures are needed. This can avoid or shorten hospital stays and lower readmission rates. Remote monitoring can help patients keep chronic diseases such as diabetes, chronic obstructive respiratory disease, heart failure, and hypertension under control while freeing them from constant medical appointments. Since these conditions and their complications drive an outsized share of healthcare spending, there are economic benefits as well.

63 "The era of exponential improvement in healthcare?" McKinsey.com, May 2019.
64 "Promoting an overdue digital transformation in healthcare," McKinsey.com, June 2019.
65 This analysis includes more than 85 use cases enabled by basic, intermediate, and advanced connectivity in areas including workflow and provider automation, paperless data systems, self-care by patients, online interactions, improved transparency around outcomes, and decision support tools.

Three of the most promising healthcare use cases running on advanced connectivity can improve the quality of care while holding down costs.



- Patients wear sensors that take readings and send them to data centers in the cloud in real time, signaling clinicians if warning signs appear
- Imaging tests are sent to cloudbased systems that use AI and advanced analytics to interpret the results, taking into account patient's genetic profile and disease history
- Data from RFID tags can feed into a central dashboard that gives a comprehensive view of hospital operations, including patient flow, staff movement, inventory management, clinical outcomes, prescribing, logistics, and utilization

We estimate that remote patient monitoring systems running on advanced networks could deliver some $70 billion to $120 billion in annual value worldwide, along with lower morbidity and greater patient satisfaction, convenience, and independence. Frontier connectivity can give these systems more sophisticated capabilities. Accurate and continuous data transmission can identify warning signs sooner and resolve them faster, with minimal interventions.

AI-enabled decision support solutions: These tools put the latest information in the hands of healthcare professionals, including constantly updated, evidence-based protocols; electronic health records; and data from patient monitoring systems. Birmingham, England, has tested out a system to connect doctors with paramedics in an ambulance. In the pilot demonstration, the doctor used a virtual reality headset and a joystick to direct the paramedic to take an ultrasound scan of a patient with a haptic glove and transmit the images back to the doctor in real time.[66]

Decision support systems can now integrate AI, which can "learn" from very large datasets (such as patient histories, test results, and demographics as well as genetic profiles). Solutions available as "software as a service" (SaaS) can give any care setting anywhere in the world decision support if the right infrastructure is in place. The combination of enhanced connectivity with high-bandwidth, low-latency networks plus expected advances in computing, storage, and sensors could enable healthcare providers to run these systems. They could create $40 billion to $70 billion in efficiencies by accelerating diagnoses, preventing errors and complications, identifying the most effective treatment protocols, and offering more personalized treatment plans.

Integrated command centers: RFID and sensor tags installed across a hospital and bar-codes from patient bracelets and clinician tags can capture real-time data. When combined with short-range connectivity, multi-department healthcare organizations can gain a comprehensive view of operations. A central dashboard can manage patient flows, ensuring that each person is in the most appropriate care setting, keeping beds available, and optimizing staff scheduling.

Advanced connectivity is the underlying infrastructure that can link multiple healthcare IT systems as well as sensors and tags within a continuum of care. It can enable faster, more accurate, and more seamless information transfers. Integrated command centers running on advanced connectivity could produce efficiencies that add up to some $40 billion to $70 billion annually.

Implications for the future of healthcare

Healthcare could look very different in a decade's time from three vantage points due in large part to enhanced connectivity:

— For individuals, enhanced connectivity will foster the wider use of remote patient monitoring, which can help people manage long-term conditions (Exhibit 11). Wearables, which can empower people to take preventive steps, rely on sensors and 5G or Wi-Fi coverage. Telemedicine can provide access to consultations on the go, at any hour, with much broader geographical coverage. Healthcare could become more convenient, more streamlined, and easier to navigate. Advanced technologies will improve patient outcomes by giving them faster access to care, more accurate diagnoses, ongoing monitoring, and rapidly adjusted treatments. As researchers study vast genomic datasets, the concept of personalized care tailored to an individual's genetic makeup could become a reality.

[66] Joe O'Halloran, "University Hospitals Birmingham demos UK's first remote 5G-powered diagnostic procedure," *ComputerWeekly,* November 15, 2019.

Exhibit 11

Connectivity gives patients the information and tools to take charge of their own health.

Improved diabetes management with a continuous blood glucose monitor sensor under skin

Higher drug adherence using a smart pill box and medication adherence app

Improved blood-pressure management using home-based remote monitoring

Timely alerts for cancer screening based on genetic profile and risk stratification analytics

Patient David is 82.

He has diabetes, hyper-tension, depression, and a history of prostate cancer

Faster outreach to patients through teleconsultation when warning signals received

Apps to encourage healthier eating, sleep management, and mild exercise as prescribed

Easier access to computerized cognitive behavioral therapy

More optimal treatment using integrated electronic health records and AI-powered decision support systems

Source: McKinsey Global Institute analysis

— Health systems should be able to use enhanced connectivity to achieve more efficient information sharing and optimize the use of limited resources. Staff can be deployed more efficiently (by, for example, relying on telemedicine instead of staffing sub-scale units in more remote locations). At the same time, providers and institutions will be able to improve patient outcomes by expanding access to expertise and coordinating care more effectively. Many large hospitals and health systems are already implementing more sophisticated digital management systems. In Southern California, the UCLA Health system is monitoring patients remotely.[67] The Torrance Memorial Medical Center uses a command center to improve patient flow and ensure that beds are ready when needed; it relies on sensors, short-range connectivity, and fiber to support the infrastructure.[68] Oxford University Hospitals relies on AI tools for image interpretation and decision support.[69] Israel's largest healthcare organization is using IoT-based "smart cabinets" to manage its inventory of medical devices and supplies.[70] Toronto's Humber River Hospital has prioritized automating as many manual tasks as possible, optimizing patient flow and freeing up staff to spend more time directly with patients.[71]

Wider economies stand to benefit from connectivity-driven changes in healthcare. In addition to creating opportunities in adjacent domains, a more connected and data-driven approach to care will make for healthier and more productive populations—with all of the economic, social, and human benefits that this implies.

67 See https://www.uclahealth.org/telehealth/remote-patient-monitoring.
68 See "Torrance Memorial Medical Center - Success in Action," case study, TeleTracking, July 2018, https://www.teletracking.com/resources/torrance-memorial-medical-center-success-in-action-case-study.
69 Pallab Ghosh, "AI early diagnosis could save heart and cancer patients," BBC News, January 2, 2019.
70 "14 hospitals accelerate digital transformation with LogiTag's solution line," LogiTag corporate press release, https://logi-tag.com/digital-transformation-with-logitags-solution-line-and-management-software/.
71 "The hospital is dead, long live the hospital!" McKinsey.com, May 2019.

Issues to be addressed

Driving adoption and changing established ways of working is not easy. The right enablers need to be put in place. Then it will take investment to accelerate the pace of change. To inject a dose of innovation on a large scale, new business models and approaches will need to be encouraged.

Some of the barriers that exist in healthcare systems today need to be overcome. These include the absence of clear reimbursement paths for digital offerings, the lack of frameworks (within and across countries) about how to invest in and fund technology-driven healthcare services, and the testing of connectivity-enabled use cases to confirm they improve patient outcomes as well as productivity. Healthcare providers themselves have limited digital capabilities, which makes them reluctant to adopt new digital offerings for both patients and healthcare professionals.

Common data standards are critical across extremely complex environments, in which multiple organizations can play a role in treating a single patient. Without them, technology modernization has been a difficult task, marked by overspending and limited quantifiable impact. Privacy and data security are paramount in healthcare; cybersecurity concerns are real and widespread. Regulatory frameworks have been slow-moving, but clear guidelines are needed to protect patients and clarify how data should be handled and how it can be shared and monetized.

It will take more than improved connectivity to realize all of this potential—and to change established, fragmented systems quickly. Innovation funding needs to become a priority for governments. Healthcare systems will need to add digital skills and roles, from system architects to data scientists and user experience designers. Countries with underdeveloped healthcare systems will need to take a thoughtful, collaborative approach to designing greenfield digital architecture—hopefully avoiding some of the legacy issues and mistakes bogging down some wealthier countries.

Domain players will need to collaborate and move beyond their traditional boundaries and silos. For instance, connecting healthcare systems could open up new business models for incumbents and make room for new players. Payors (or providers taking on the role of payors) can be the drivers of change, drawing on patient data, establishing new incentive structures, and potentially taking more of the risk (and reward) associated with technology investment. Employers, too, may take on a greater degree of risk and reward themselves in some markets, perhaps collaborating with providers to serve their employees and capture more value from virtual and preventive care. Technology and connectivity providers will play a bigger role in healthcare and have an opportunity to carve out some niche markets. But all stakeholders need to solve the issue of interoperability across systems and solutions—and there may be only be a few winners here, as scale matters.

Frontier connectivity is a platform for implementing Industry 4.0 technologies in manufacturing and other advanced industries

A wave of technology advances collectively known as “Industry 4.0” has been driven by an explosion in the volume of available data, developments in analytics and machine learning, new forms of human-machine interaction (such as touch interfaces and augmented-reality systems), and the ability to transmit digital instructions to the physical world.[72]

These complementary technologies can run smart, cost-efficient, and automated factories. But where connectivity has been a barrier, a variety of new standards (such as WLAN 7, BT mesh, fiber, and high-band 5G) could accelerate the shift to a more digital form of manufacturing.

[72] For more on this new era of technology in manufacturing, see *The great re-make: Manufacturing for modern times*, McKinsey.com, June 2017; and *Digital manufacturing: Escaping pilot purgatory,* McKinsey Digital, July 2018.

Today most factories and plants have fixed and industrial Wi-Fi networks that are relatively inexpensive but have several drawbacks. Wi-Fi often encounters interference, particularly in dense settings, and fixed connections are complex to manage and costly in large manufacturing environments. With the introduction of high-band 5G networks, manufacturers will gain a reliable alternative that enables critical communications, such as the wireless control of machines and manufacturing robots. In fact, high-band 5G may become the technology of choice for both industrial mobile applications and manufacturing settings where a fixed connection is unsuitable, such as those dispersed over a large area or including wide movement of assets.

One option for industrial companies to achieve frontier connectivity is building private 5G networks. Because data is processed without touching public networks, companies that build private networks can protect sensitive production-related data and enjoy the flexibility and reliability to develop proprietary applications. Automakers already use private 5G networks to link data across production systems and track products on assembly lines. Regulators in several countries are facilitating the creation of private 5G networks for industrial companies by allocating spectrum for their use. When spectrum allocation begins, large manufacturers will probably set up private 5G networks right away. But it may take another three to four years for mid-sized companies to follow suit.

Use cases and the value at stake

The business value resulting from use cases running on improved connectivity could generate from $400 billion to $650 billion of GDP impact by 2030. Most of the applications in manufacturing and other advanced industries requires the kind of speed, latency, and device density that frontier high-band 5G can support.

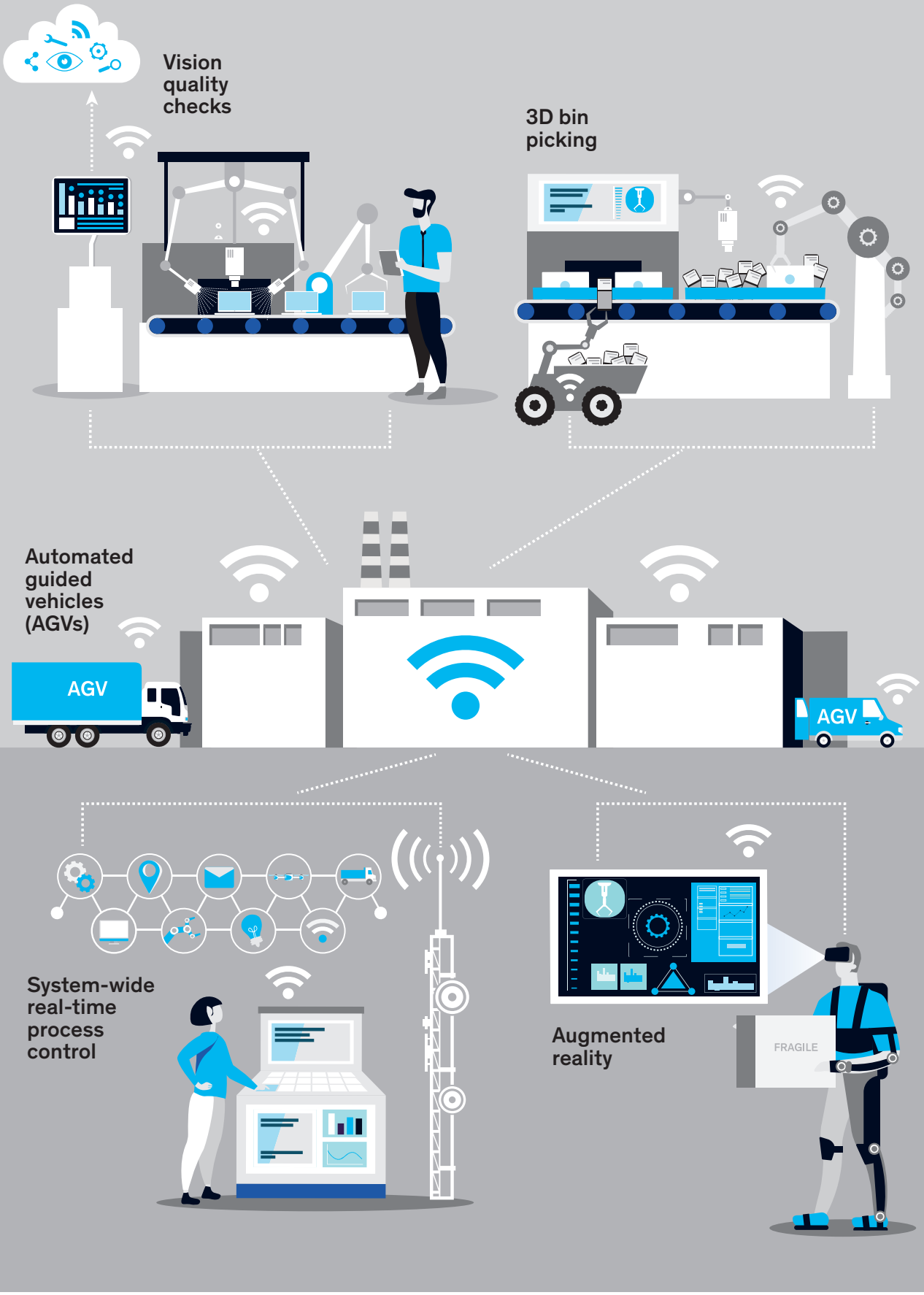
Some of the most compelling manufacturing use cases that can run on public or private high-band 5G networks include:

Automated guided vehicles (AGVs): Factories now rely mostly on transport vehicles that either operate in fixed paths or have only basic capabilities for optimizing routes. These vehicles are equipped with sensors to assist with navigation and help prevent collisions. Frontier connectivity paves the way for the deployment of large fleets of next-generation AGVs, which will connect with cloud or edge servers that can support advanced analytics. These vehicles can review data to make sophisticated navigation and coordination decisions based on the real-time context of other connected machinery and AGVs. Frontier connectivity offers the low latency needed for safety stops and real-time navigation. We estimate that the combination of enhanced connectivity and automated guided vehicles could generate $130 billion to $200 billion in business impact by improving productivity in logistics.

3-D bin picking: In most factories, machines pick parts from bins by taking items from a fixed location. With advanced or frontier connectivity, robots will be able to use sophisticated vision systems to locate parts regardless of their location. Pickit, for example, has created robots equipped with HD cameras that can locate parts with computer vision. Since advanced and frontier connectivity enable data analysis in the cloud or at the edge, the robot itself requires minimal processing power. We estimate that 3-D bin picking can generate $30 billion to $50 billion through improved productivity.

System-wide real-time process control: Companies can capture significant value by using advanced analytics to optimize and adjust processes—not only on select assembly lines but across multiple plants. In many cases, companies can retrofit old equipment and reliably connect existing machinery and sensors to perform sensor-driven analyses. This is particularly important in process industries, where companies typically retain the same equipment for many years, with complex and costly fixed networks that extend across large sites. To enable real-time control, they need the kind of wireless, reliable, and low-latency communication that frontier connectivity can provide. Real-time process control can significantly reduce defects, rework, and breakdowns, creating some $130 billion to $200 billion in value.

Advanced connectivity can help achieve savings all along the value chain of the manufacturing industry.



Augmented reality: Workers can use AR glasses that display instructions in their visual field to guide tasks such as quality inspections. These glasses must process data in real time to provide a seamless and responsive experience. The low latency and high-speed communication of high-band 5G will also allow data processing to occur on the edge, which decreases costs and increases energy efficiency. Augmented reality in production, logistics, and R&D can generate some $45 billion to $75 billion in value.

Vision quality checks: AI can significantly improve visual inspections. Frontier connectivity can boost the performance of real-time analytics within vision quality systems so that deviations are spotted quickly, before multiple units are processed. While development of traditional machine vision models is complex and requires about eight months, AI algorithms can be trained and deployed within weeks. We estimate that vision quality checks can generate $50 billion to $100 billion through improved productivity.

Strategic implications for industrial companies

While we do not expect a disruption in the industrial manufacturing value chain, established players have an opportunity to capture significant value. We expect the number of 5G-specific IoT devices to take off in a few years' time, with strong deployment in manufacturing and processing (Exhibit 12). Industrial firms need to develop a strategy now for getting started.

Given the breadth and complexity of 5G systems, manufacturers often turn to technology providers to define a "just right" solution that delivers the best return on investment. Industrial automation providers and telecom operators (or private network specialists) can be key partners in laying the right foundation. Application and solution providers contribute to the implementation of the actual features.

Early movers have already started 5G partnerships. Daimler, for example, has partnered with Telefónica and Ericsson to implement a private 5G network for automobile production.[73] Audi and Ericsson have teamed up to implement 5G technology in the "Audi Production Lab" in Gaimersheim, while Volkswagen partnered with AWS to build an industrial cloud for IoT devices.[74]

On the supply side, industrial automation players will want to make their own products 5G ready. A good starting point for the short term would be leveraging the experience of customers who are early adopters and apply those lessons to product enhancements. To develop a better understanding of market development and customer needs, sales teams need to identify emerging frontier connectivity use cases and feed those insights into product portfolio development. Given the uncertainty surrounding which applications will be widely adopted and when, automation players will need to review their offerings frequently. In the longer term, once frontier connectivity becomes broadly available, a comprehensive portfolio of 5G-enabled products might be beneficial, with a modular approach that can optimize costs.

Issues to be addressed

When technologies are new and unfamiliar, companies may question the business case for adopting them. Struggling to clearly evaluate the bottom-line effect against the expected cost of implementation is a real hurdle for manufacturing companies considering frontier connectivity networks and the array of technologies that would run on them. Manufacturers have large, extensive asset bases with major sunk costs, and upgrading equipment and processes is not easy. Adoption and change in large manufacturing companies can be slowed by the number of decision makers involved and a top-down emphasis on digitization and automation.

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73 "Mobile network of the future. The world's first 5G network for automobile production," Daimler.com, July 2019.

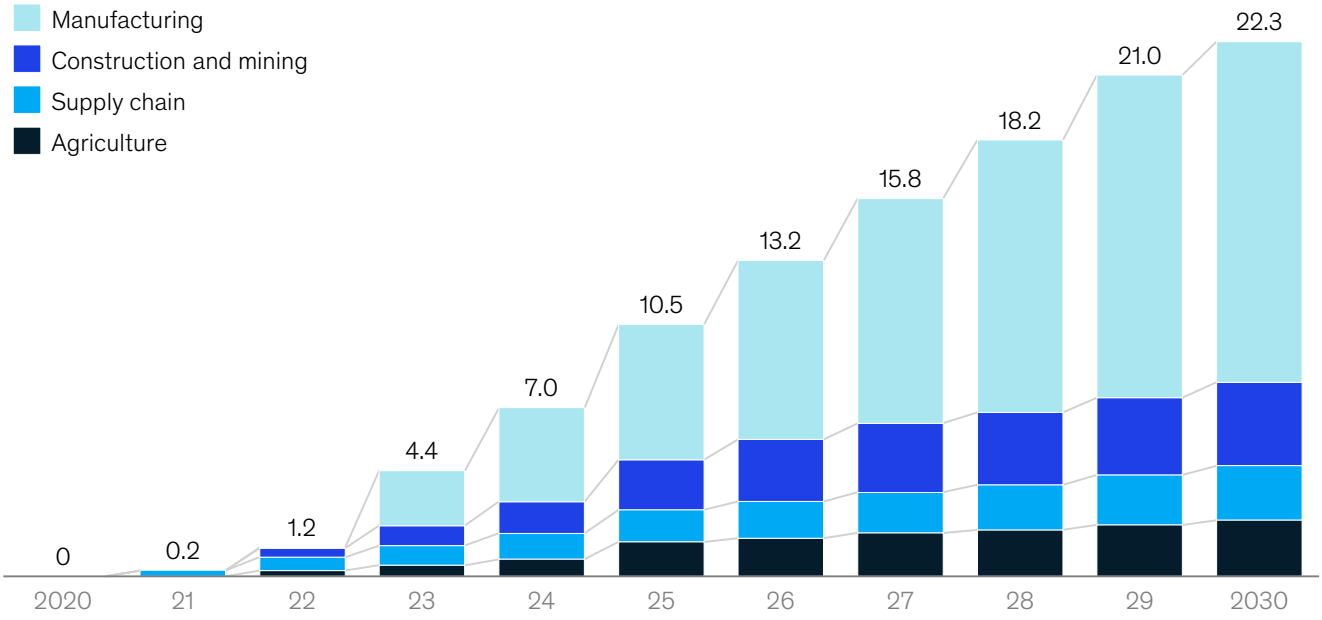
74 "Audi and Ericsson to pioneer 5G for automotive manufacturing," Ericsson corporate press release, August 2018; and "Volkswagen and Amazon Web Services to develop Industrial Cloud," Volkswagen corporate press release, March 2019.

Exhibit 12

Sales of 5G IoT endpoints are expected to soar as Industry 4.0 applications gain traction for use cases identified in this report.

Forecast 5G IoT unit sales for select Industry 4.0 use cases

Million



Source: "The 5G era: New horizons for advanced electronics and industrial companies," McKinsey & Company, February 2020; McKinsey Global Institute analysis

Implementing a frontier connectivity use case will often require collaboration with new types of partners beyond the usual supplier ecosystem.[75] Advanced warehouse management using automated guided vehicles, for example, involves infrastructure providers, technology providers, vehicle and equipment manufacturers, and a dedicated team for final implementation and ongoing operation. New types of training may be needed.

Data security is paramount for most industrial companies, which argues for building private networks rather than relying on public networks. But this is a costly strategy and may be prohibitive for mid-size manufacturers.

Advanced connectivity and the falling price of key technologies sets the stage for transformation on a larger scale in retail

The way we shop is very different today than it was a decade ago. E-commerce continues to post double-digit growth each year, reaching some $3.5 trillion in worldwide retail sales in 2019.[76] But online shopping is only part of the story. Technology and automation are now at the heart of how the entire retail value chain is evolving.

[75] "Making the most of the ecosystem economy," McKinsey.com, October 2017.
[76] Data from Internet Retailer.

For customers, digital increasingly drives choices even when purchases are made in stores. For instance, roughly half of shoppers have used omnichannel services (such as checking online to see whether a product is in stock before going to a store).[77] Just over half of US shoppers log onto Amazon for their initial product research. For retailers, analytics and automation are driving efficiency improvements in forecasting, inventory management, back-office operations, and marketing.[78]

Multiple elements of the retail environment are changing. Customers increasingly take their shopping cues from digital influencers and purchase through social media platforms. Almost one-third of consumers actively flip through their social media accounts while shopping.[79] Customer expectations are quickly evolving, with millennials and Generation Z finding e-commerce more convenient and relevant and prioritizing it over in-store experience. This shift toward digital touchpoints and omnichannel business models is set to continue. Traditional domain boundaries are blurring as retailers experiment with cross-domain partnerships, subscription models, delivery, maintenance, and new kinds of services and experiences.

In this rapidly changing and more digital world, brick-and-mortar players want to provide seamless convenience and the kind of personal experience that customers have come to expect based on new standards set by e-commerce players. As retailers respond to this disruption, they are doing so by integrating technologies across their value chain to reinvent the physical store experience.[80]

The most promising use cases involve capturing data and analyzing it in real time—and with a high degree of reliability and security. Functions such as computer vision cannot work with any lag in connectivity. Instant and secure connections are required to feed information from across the entire value chain into backend computing systems.

Three types of technologies are pivotal. They include multiple types of sensors, passive and active RFID trackers, NFC, Bluetooth beacons, and cameras that enable data collection; substantial storage capacity to handle reams of data on customers and store operations; and enhanced computing power to process this data and run functions powered by artificial intelligence (such as computer vision, natural language processing, machine learning, recommendation algorithms, and robotics). The price of these technologies has been decreasing over the past 10 years, and this trend is expected to continue over the next decade.[81] These trends could soon pass a tipping point in terms of penetration throughout the retail domain.

Use cases enabled by advanced connectivity

Use cases in retail involve a few key technologies: sensors, trackers, computer vision, AI, advanced analytics, and smart interfaces. More than 90 percent of them will come to life with advanced connectivity like fiber, low- to mid-band 5G, Wi-Fi 6, or short-range communication systems such as RFID automated scanners. High-band 5G is not a prerequisite, although it could boost efficiency. The business value resulting from these use cases could generate $420 billion to $700 billion of GDP impact by 2030.

77 *The state of the connected customer,* Salesforce Research, 2019.
78 For more on these shifts, see "A transformation in store," McKinsey.com, May 2019.
79 McKinsey New Age Consumer Survey, April 2019.
80 "Ready to 'where': Getting sharp on apparel omnichannel excellence," McKinsey.com, June 2019.
81 See Exhibit 2, earlier in this report.

Use cases span the entire retail value chain.

Three primary types of use cases in retail illustrate the value of connectivity:

End-to-end product visibility: The shift in customer expectations is pushing retailers toward an omnichannel operating model. Fulfilment models have evolved over the years to offer consumers a plethora of choices. They can buy online and pick up in a store, ship from store to home, ship from distribution center to home, ship from store to store, drop-ship, and more. As a result, retailers face the challenge of managing inventory accuracy at the product level.

There are efficiencies and savings waiting to be captured across the supply chain—and visibility alone can unlock a great deal of it. Multiple type of levers can be deployed, including next-generation warehouse management, real-time transportation visibility, out-of-stock mitigation, shrinkage reduction, or on-shelf inventory tracking. Connectivity-enabled end-to-end visibility across the value chain could generate cost savings of $100 billion to $160 billion and boost revenue by $60 billion to $100 billion.

Retailers can use different types of technologies to gain the information and insights they need. Active RFIDs at the product, pallet, or container level, for instance, enable fully automatic scanning of products at scale to optimize warehouse operations. Warehouse management tools alone could generate about $5 billion to $10 billion in cost savings.

Combining trackers with computer vision and weight sensors allows retailers to monitor every store shelf with precision, reducing instances of stock-outs and feeding into forecasting. However, computer vision requires significant computing power and an ultra-high-speed connection. Automated and real-time inventory management could generate up to $60 billion to $100 billion in additional revenue by ensuring that stock does not run out.

Bringing this same combination of trackers and computer vision into stores, retailers could identify when products are missing and send automatic push notifications to associates. On-shelf inventory tracking could lead to as much as $35 billion to $55 billion in cost savings, significantly reducing time associates spend on manual inventory checks.

As the price of trackers and sensors comes down, suppliers would have incentive to apply them to a wider range of products. They, too, can benefit from end-to-end visibility; access to more customer data can help them improve their own processes and bargaining positions. Companies in the consumer-packaged goods industry may become increasingly willing to source-tag more products to capture more data themselves. This could produce a virtuous circle.

Frictionless in-store experience: E-commerce has raised the bar for convenience, and physical stores have to meet it in order to remain relevant. We estimate that designing a more frictionless customer experience could produce $150 billion to $250 billion in cost savings.

AI-powered interfaces and geofencing can point shoppers to the products they want and remember their preferences, for example. Improved connectivity and the growing affordability of the underlying technologies set the stage for deployment on a much larger scale. Augmented reality can help shoppers understand exactly what they are buying and how it will perform in different environments; it could even enable customers to sit back and try on clothes with interactive mirrors.

One of the most promising conveniences would be eliminating checkout. RFID scanners, payment beacons, and computer vision can enable shoppers to walk out of stores and pay seamlessly for the merchandise they are carrying. Their accounts can be charged automatically without waiting in checkout lines. Checkout optimization, powered by trackers, AI, and machine learning, could generate up to $125 billion to $200 billion in cost savings.

Enhanced personalization: Advanced connectivity can also support a new level of personalization in retail. Using advanced connectivity to deliver a high-tech personal experience in stores could increase revenue by $230 billion to $400 billion.

Personalization can boost total sales by 15 to 20 percent.[82] Yet a recent McKinsey survey found that fewer than 10 percent of companies were pursing such strategies in a systematic way beyond their digital channels. Doing this in stores represents a significant opportunity. Covergirl, for example, has created a flagship store with "glam stations" for trying different cosmetics virtually by applying them to the shopper's own image.[83]

Real-time personalized promotions in stores could be implemented in several ways. Associates can use customer insights to create personalized offers (perhaps relying on next-product-to-buy algorithms). Personal shoppers can use AI tools to propose very targeted product recommendations based on omnichannel data. Alternatively, location data and biometric sensors can be used to guide customers to the products they are looking for; it can also push offers to customers when they travel within proximity of a store. All together, these opportunities can increase foot traffic into stores and then direct customers to personalized offerings, and altogether lead to up to $140 billion to $230 billion in increased sales.

Implications for the retail domain

The retail domain has already experienced significant disruption from online retail and cross-domain players. Traditional retailers are being forced to move quickly, add new digital capabilities, and revitalize the store experience. There is likely to be an increasing gap between large players with the scale and financial capacity to own major parts of the technology required to support their operations and relatively smaller players.

Across individual markets, retail competitors are likely to have the same access to advanced connectivity. The differentiating factors will be the development of applications and solutions as well as the capabilities integrated by retailers themselves. In a world with advanced connectivity, retailers are sorting into three categories, with different levels of capital availability and technical capabilities (Exhibit 13).

Among large-scale players, the online pioneers are well positioned to integrate cutting-edge technologies into their value chain. They have the computational power (and the talent) to use new types of advanced analytics to segment customers at an increasingly granular level and better address their needs. Amazon, for instance, is even playing an outsized role in providing technology solutions to others across the ecosystem, including via AWS with AI-powered applications and block-chain solutions. Online incumbents that want to expand a physical presence can build strong customer data platforms to bridge between online and offline channels, freeing them to focus on investment and staffing. They could even sell these platform solutions as a service to other players in the value chain (although not retail competitors).

The second category is made up of large traditional players. Although they are not digital natives, they are still well positioned to implement use cases. They have the scale necessary to derive real value from data capture and applications, but they may need to develop a stronger technology backbone and beef up capabilities to do so. These companies can make acquisitions or form partnerships to gain in-house applications quickly. Some of the largest companies are aiming to develop their own integrated ecosystem along the lines of what the largest online pioneers have created. Kroger, for instance, acquired the data analytics subsidiary of Dunnhumby (now 84.51°); it integrated the data capture and analytics capabilities in its own operations and also monetizes this service to suppliers.[84] Other players

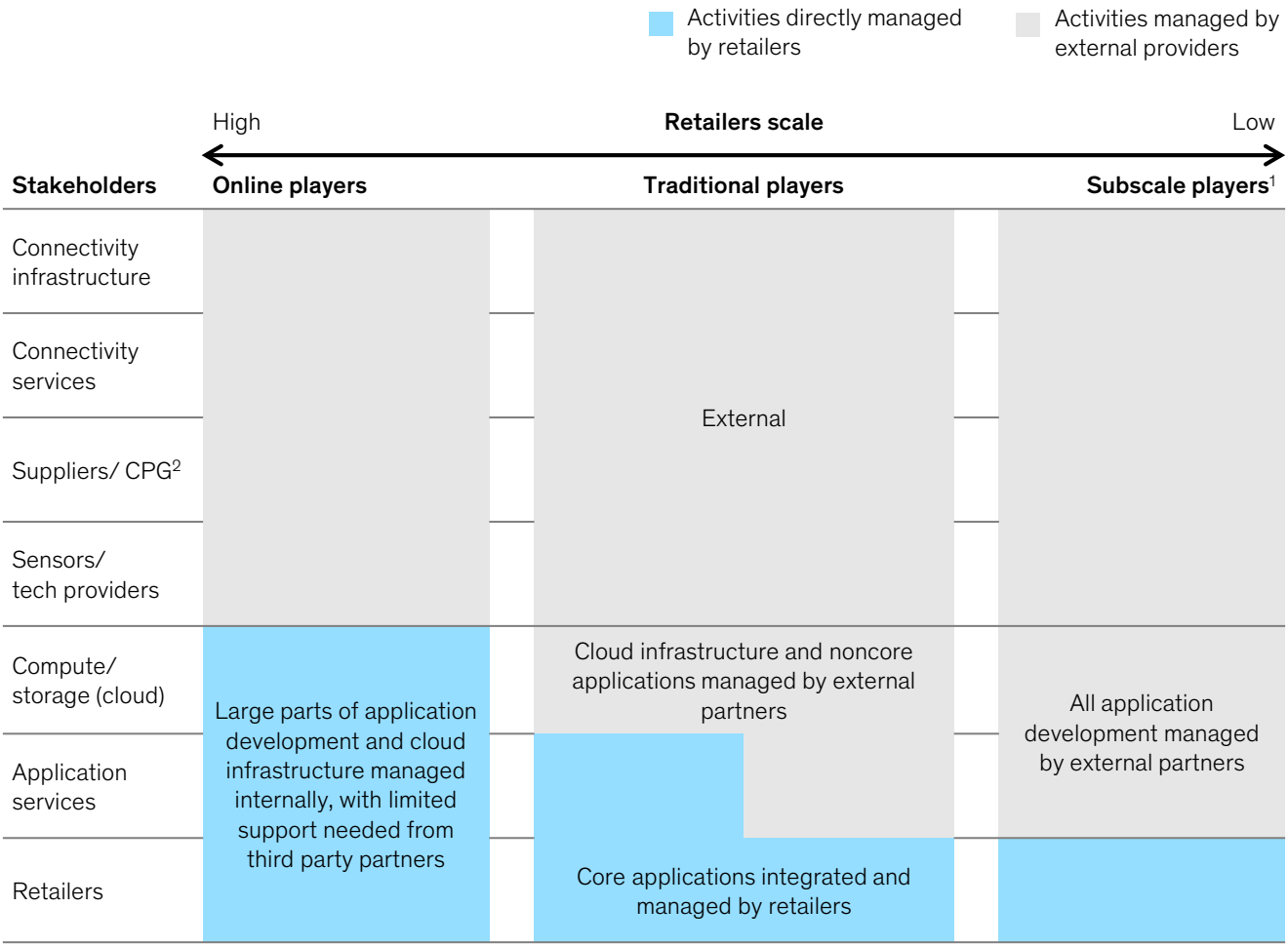
[82] "The 2019 holiday season: Shoppers are ready to spend, but retailers need to personalize," McKinsey.com, October 2019.
[83] "The future of personalization—and how to get ready for it," McKinsey.com, June 2019.
[84] "Kroger acquires Dunnhumby's tech assets to form 84.51," DMNews.com, April 2015.

might turn to external providers for their technology needs. Some are partnering with connectivity and technology service providers to develop systems and applications based on their specific needs and parameters, which could include store and geographic specifications, customized applications, or anticipated implementation challenges. The retailers in this group can take advantage of their brick-and-mortar footprint by piloting and testing use cases, then implementing them at scale across their store networks.

Subscale players have to find alternative strategies. They have limited access to capital and may lack tech capabilities, but they can adopt turnkey solutions from external providers. Entering into service agreements with outside providers could be an option to keep the capital investment manageable; another could be creating partnerships to test concepts. Companies like Pensa Systems rent on-shelf inventory monitoring services that use drones and computer vision. Standard Cognition can set up checkout-free payment systems in any retail store with the company devices and AI. There is also room for intermediaries to offer a "one-stop-shop" service, bundling multiple offerings into turnkey solution suites for retailers. Smaller retailers might be able to use their investments in tech innovation to differentiate themselves and take their in-store experience to the next level, with technologies like virtual fitting rooms, which could also optimize inventory.

Exhibit 13

The level of services integration would vary across retailers depending on their scale and main distribution platforms.



1. Includes large holdings with multiple brands not leveraging scale on the retail activity.
2. Larger-scale retailers (in terms of ordering) are better positioned to negotiate with suppliers and makers of consumer packaged goods to equip products, pallets, and containers with tracking systems.

Source: McKinsey Global Institute analysis

Issues to be addressed

To make technology investments pay off, use cases need to be implemented across the board, not at one point in the value chain. For example, using RFID tags and detectors exclusively for in-store inventory management would produce only a fraction of the value that could be generated by an integrated solution spanning from distribution centers to on-premises stock rooms, on-shelf smart replenishment processes, and check-out optimization. Retailers historically have tended to consider their capital investments, benefits, and cost structures in silos. They will need to overcome any lack of internal alignment and look for holistic implementation strategies, making the required investment at the company or group level.

To bring digital into stores and achieve this vision of connectivity, retailers need access to the right technology at an affordable price. Margins are thin in retail, and cost has been a major barrier to date. Only 40 percent of retailers have posted rising gross margins and EBIT margins over the past few years. Looking at the top and bottom quartile of retailers, margin performance is the main differentiating factor that stands out. From a cost perspective, retailers tend to invest in technologies that will generate returns on investment within a three-year timeframe, limiting heavy spending on others that are more speculative and may take longer to pay off.

Even if cost considerations are addressed, retailers tend to be limited in their willingness to make big bets due to the constant pressure on earnings and margins. McKinsey research has found that 80 percent of retailer investments continue to be in legacy areas. Many tend to test initiatives on a limited scale and roll them out slowly; vendors, too, are largely still in the pilot phases. The challenge will be creating an integrated technology vision and pursuing it on a large scale.

Implementing use cases with systems involving facial recognition, location tracking, or instant payment needs careful thought, with strong safeguards around data security and privacy. Some customers may embrace the convenience of personalized offers and instant payment, but others are wary and may be put off. Regulation will define the rules, and since it may vary by region, it can introduce complexity for retailers and hinder the deployment of some use cases.

4. Overcoming the hurdles

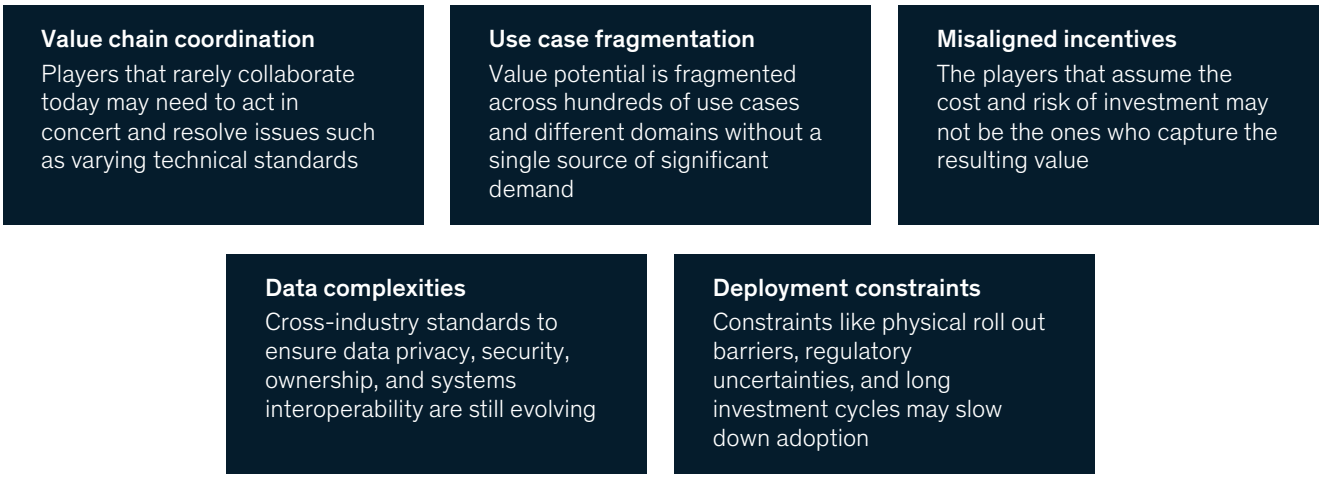
The potential associated with connectivity is big and promising. Realizing this value does not require additional technological breakthroughs—most of it can be achieved using technology that has already existed for quite some time. Yet end users in most commercial domains are not adopting new technologies and use cases at the scale and speed one might expect. Our analysis of the four large commercial domains profiled in Chapter 3 suggests that the barriers keeping businesses from realizing the full potential of connectivity use cases are not new—and cannot be overcome with technological progress alone.

In a world where future economic growth depends on finding new avenues for improving productivity, the hurdles slowing both network deployment and the widespread adoption of use cases urgently need to be addressed. In this chapter, we discuss some of the issues that surfaced in our analysis of mobility, healthcare, manufacturing, and retail. While the barriers vary somewhat in each commercial ecosystem, some common themes emerge. We have categorized these broader issues into five groups (Exhibit 14). They include both demand-side challenges (such as use cases that require coordination between different entities) and supply-side challenges (such as misalignment of risks and incentives in deploying connectivity infrastructure).

These are thorny and persistent issues. But they are not impossible to overcome, and initiatives are already under way to address some of them. In this chapter we identify some of the hurdles and potential solutions.

Exhibit 14

Longstanding hurdles continue to hold back the promise of connectivity.


Value chain coordination
Players that rarely collaborate today may need to act in concert and resolve issues such as varying technical standards
Use case fragmentation
Value potential is fragmented across hundreds of use cases and different domains without a single source of significant demand
Misaligned incentives
The players that assume the cost and risk of investment may not be the ones who capture the resulting value
Data complexities
Cross-industry standards to ensure data privacy, security, ownership, and systems interoperability are still evolving
Deployment constraints
Constraints like physical roll out barriers, regulatory uncertainties, and long investment cycles may slow down adoption

Source: McKinsey Global Institute analysis

Harnessing demand coordination and aggregation

Use cases in any single commercial domain may involve coordinating multiple actors (from firms in different industry verticals to government agencies). Many of them do not regularly communicate and collaborate today. Now they may need to align on common technical standards for systems to work—and these standards are still evolving, even in the most developed markets. In most countries, governments can play a coordinating or convening role, but the private sector shoulders most of the weight of solving these issues and forming smoothly functioning ecosystems.

In health care, for instance, remote monitoring has clear benefits for patients, but it involves medical institutions, med tech providers, payors, and public agencies. Common protocols, standards, and reimbursement models will need to be defined. In mobility, vehicle-to-infrastructure and vehicle-to-vehicle warning systems involve public infrastructure providers, rival automotive manufacturers, connectivity providers, technology players, and equipment manufacturers.

These are only two of the use cases with complex interdependencies. There is a real possibility that connectivity providers could build the network infrastructure, but adoption may not follow if coordination fails. The time and resources involved in this coordination adds to the cost of the infrastructure itself. The risks are magnified in domains where the capital requirements are especially high.

The coordination challenge is magnified by the fragmented nature of the many potential use cases. The value that can be produced with enhanced connectivity is substantial across an entire economy, but it is spread across hundreds of use cases and many industries—and together, they may represent only a relatively small fraction of total value in a given domain. Since the demand is so fragmented, no single actor is able to drive momentum and stakeholders may not see enough value potential to engage. In addition, these use cases are not always core priorities for industry players, especially those who are not as far along in their digital transformation journey.

All of this can contribute to companies taking a wait-and-see approach or stalling in a never-ending "pilot purgatory." Retailers and manufacturers, for example, could both benefit from advanced computer vision, but the value it could produce may not be significant enough for companies in these sectors to clamor for someone to deliver these services right away.

Addressing these issues may require companies to rethink business models and their roles in their respective value chains. There is an opportunity for an actor to play a coordinating role, galvanizing multiple stakeholders across broader ecosystems to move forward toward a common goal. It is unclear who will lead the way and connect the dots across various domains—but such an actor could potentially address both coordination and fragmentation. Large multinationals, industry groups, national and local governments, and other major industry actors such as health systems can play a role in aggregating demand and leading cooperative efforts. Tech giants and connectivity providers themselves may also be candidates.

A number of telecom companies worldwide are beginning to play this type of role in smart city partnerships. In the mobility space, many key players in the automotive and smartphone industries have formed the Car Connectivity Consortium to collaborate on setting global standards for in-vehicle connectivity.[85] In some regions, and in some domains providing public goods, governments may step in. In Singapore, Singtel, Ericsson, and Singapore Polytechnic partnered to establish the 5G Garage, a networked facility where providers, business customers, and other stakeholders can collaborate and test out use cases; its goal is to help launch a wider 5G ecosystem.[86]

[85] See carconnectivity.org.
[86] "Singtel, Ericsson and Singapore Polytechnic open Singapore's first live 5G facility," Singtel.com, January 2019.

Misaligned incentives can slow down adoption in commercial domains

In the commercial domains we studied, there are several examples of misaligned incentives. The company that takes on the cost of upgrading assets and systems and does the heavy lifting of implementation may not be the one that captures the most value, or even extracts value commensurate with the risk. For some use cases, it is unclear exactly *who* will capture the value.

For instance, healthcare innovations running on enhanced connectivity could improve patient outcomes and improve efficiency. But while hospitals and health systems need to invest, add new talent, and change the way they work, much of the ultimate financial benefit could go to insurers, patients, and the public sector. To solve this issue, some insurers are starting to partner and invest.

The same story could play out for connectivity providers. Misaligned incentives have the potential to slow future rollouts and upgrades. Connectivity providers are often the actors who must put up substantial risk capital to build advanced networks, but they are not necessarily positioned to reap the benefits. Consumer internet, media, and advertising companies have long profited from offering "over-the-top" services that run on networks built and maintained by connectivity providers, but the providers themselves have struggled to monetize this activity in a proportional way.

For established companies and start-ups alike, attempting to re-align market incentives (or profit from the status quo) can be a gamble that would require significant upside opportunity to merit the risk. However, the far-reaching economic and social benefits of certain use cases may be significant enough to compel public-sector actors to play facilitator for those actors who dare to take a chance. The options and levers available to governments to help overcome these challenges vary by country, depending on its ambitions, available resources, and other trade-offs such as those related to competition or consumer protection policy.

One potential solution is directing more public funding into basic R&D to encourage experimentation.[87] Another may be regulatory solutions to improve the investment case for connectivity providers. For example, on the cost side, network sharing stands out as a solution that has proven successful with previous generations of cellular connectivity. It is expected to have even stronger potential with 5G, by reducing the cost of small cell deployment significantly while enabling device and equipment manufacturers to achieve better economies of scale.[88]

Some governments have used direct support and subsidies to address incentives. China, for example, has made huge investments in its fixed and cellular networks for the past several years with the aim of offering 5G in all major cities and switching a quarter of mobile subscriptions to 5G by 2025. Korea's "5G Plus" strategy includes $27 billion in tax breaks and government investments by 2022.[89] Other direct support initiatives include subsidizing equipment, providing tax incentives, and funding 5G R&D and testbeds. In other countries, subsidies may be necessary to address the urban-rural divide. In the United States, the Federal Communications Commission plans to devote $20 billion to improving mobile connections in rural areas.[90]

[87] *Innovation and national security: Keeping our edge,* Independent task force report number 77, Council on Foreign Relations, 2019.

[88] *The road to 5G networks: Experience to date and future developments,* OECD Digital Economy Papers, number 284, OECD Publishing, Paris, 2019. See also "Network sharing and 5G: A turning point for lone riders," McKinsey.com, February 2018.

[89] *5G launches in Korea: Get a taste of the future,* Samsung white paper, 2019.

[90] Todd Shields, Jennifer Jacobs, and Justin Sink, "Trump says US 'must win' race to develop 5G infrastructure," *Bloomberg,* April 12, 2019.

Rapid adoption of use cases depends on resolving concerns around data privacy and security, ownership, and interoperability

The economic value of connectivity is closely linked with the value of data flows. Use cases that promise radical personalization of products (such as in retail) or that drive productivity through machine-to-machine communication (such as in manufacturing) rely on the collection of large, rich, and specific data about consumers and businesses. Widespread adoption of these use cases requires assuaging individuals' valid concerns about privacy, and businesses' concerns about data confidentiality and integrity. Adoption also requires addressing data security risks, ranging from unauthorized access to personal or business data to the safety of physical assets controlled by connectivity-enabled IoT solutions.

Data ownership rights and interoperability concerns are also potential hurdles to adoption, especially with IoT applications.[91] Data interoperability can be potentially addressed by encouraging open standards, or by building platforms that can translate between different data formats. But in addition to interoperability, adoption of use cases also requires that all participants in a commercial domain have a common understanding of ownership rights to data produced by various connected devices. For instance, who has the rights to health data from a patient's monitoring device—the patient, the provider, the device manufacturer, or some other party? Who gets to decide how this value should be shared? Such concerns are not limited to healthcare: they extend to use cases that we analyzed in manufacturing, retail, and mobility domains as well.

One potential path to overcoming data complexity hurdles is to create common data standards. Industry associations, technology suppliers, and policy makers can collaborate to create such standards. Translation/aggregation platforms are also needed to manage communication among different applications. They can enable the uses cases described and unlock the value at stake.

In addition to defining interoperability standards achieving the potential of connectivity requires improvements in security and methods for ensuring privacy, protection of intellectual property, and assignment of data ownership. Policy makers can play a key role in these areas as they are intertwined with many areas of regulatory and government responsibility.

The speed of deployment is influenced by factors such as financial constraints, regulatory uncertainty, and legacy assets

Some of the issues holding back progress include legacy barriers and financial constraints. Domain players and connectivity providers alike may have an extensive legacy asset base that will be expensive to upgrade. Even among B2B players such as retailers, manufacturers, or wholesalers, adopting connectivity-enabled use cases can be delayed by long capital investment cycles. In the past decade, many firms have postponed asset upgrades due to weak growth and an uncertain investment outlook.

Regulatory uncertainty also needs to be resolved around broad issues as well as domain-specific questions in areas such as mobility and healthcare. For connectivity providers, practical constraints like spectrum availability, access rights to public infrastructure, and power density limits are persistent challenges that often have to be overcome at the local level.

The realities of enhancing and rolling out networks are substantial, but connectivity providers are not alone in rising to the task. Governments have a stake in accelerating network buildouts and upgrades to capture the productivity benefits and achieve more inclusive growth. Policy makers cannot solve all of the issues, but they can address some of the barriers.

[91] *Unlocking the potential of the Internet of Things*, McKinsey Global Institute, June 2015.

Spectrum availability is one, as unused spectrum blocks within the priority bands for 5G deployment are increasingly hard to find. Policy makers will need to carry out the task of relocating other applications outside those priority bands. They can also facilitate and encourage spectrum sharing between connectivity providers and with other applications.

Governments can also establish clear and thoughtful legal frameworks around controversial topics such as power density limits and access rights to public infrastructure for densified network installations. This could remove some of the uncertainty surrounding the feasibility, cost, and returns of rollout—and once connectivity providers gain clarity, they will be more inclined to move ahead.[92] In addition, specific issues need regulatory certainty to clear the way for implementation in areas such as healthcare and mobility.

[92] Ibid.

5. The connectivity gap across countries

Even if most of the market issues described in Chapter 4 are resolved, the business case for building advanced and frontier networks looks very different across countries. It also varies sharply between urban and rural areas, even within the most promising national markets for frontier connectivity.

Barring any major intervention from policy makers or other investors, connectivity providers will naturally limit their network build-outs to those areas where they can make their capital investment pay off. They will have to weigh the expected revenue and profitability, the cost of capital, population density, the cost of deployment per capita, and more. Connectivity providers will have to prioritize their broader portfolio of capital expenditures, assessing the share they allocate to enhanced connectivity in light of the multiple technology cycles they must sustain. Their financial health, their annual spending levels, and the maturity of the market for advanced and frontier connectivity will determine each country's timeline for rollout.

The countries that are in the forefront today can expect superior performance and new capabilities that will remain out of reach for trailing countries. Connections everywhere will become faster and more reliable over the next decade, but not to the same degree. By 2030, we estimate that roughly 80 percent of the global population could have advanced coverage or better, with a quarter of the world's population covered by high-band 5G networks.

When it comes to connectivity, every country is not equal

We define four country archetypes based on a number of factors: revenue dynamics, such as average revenue per user and level of data usage; cost dynamics, such as the quality and extent of existing telecom infrastructure as well as urban density; and market dynamics, including differences in regulation and competition.

Based on these characteristics, we classify countries into four distinct groups:

— **Pioneers:** These countries, typified by Japan, South Korea, and the United States, have consistently led the pack in connectivity. They are starting to deploy high-band 5G in select parts of major cities.[93] They will likely remain in the forefront, thanks to mature fixed infrastructure and the relatively strong financial positions of operators.

— **Leaders:** Countries including the United Kingdom, Germany, France, and Canada are consistently close behind the pioneers. But operator investment may be constrained in these markets since price competition has reduced margins. Their providers generate lower average revenue per user than their peers in pioneer markets.[94]

— **Followers:** Countries such as Brazil, Turkey, and Poland, are about two to four years behind the pioneers, but advanced and especially frontier networks are likely to be limited

[93] *State of Broadband Report 2019*, International Telecommunication Union and United Nations Educational, Scientific and Cultural Organization, September 2019; "Verizon 5G Ultra Wideband service available in more cities," Verizon News, January 2020.

[94] McKinsey Global Institute analysis of connectivity provider annual reports and GSMA Intelligence data.

to major urban cores only. Like operators in leader markets, those in follower countries may find it harder to support the large capital investment required to build sophisticated networks. As a result, existing fixed infrastructure is often inadequate, even in urban areas. Over the next decade, the focus in follower countries is likely to be on advanced mobile networks (low- to mid-band 5G) and the expansion of fiber. Depending on the affordability of service, LEO satellites could bridge coverage gaps in rural areas.

— **Trailing markets:** Many African nations fall into this category, as well as Iran and Bolivia. These countries tend to have limited basic connectivity infrastructure and are unlikely to deploy advanced mobile networks in the near term. That said, their populations have lower data usage—and moving later may help them benefit from improved economics. Although LEO satellites may provide connectivity options for most of the population, the cost of deployment and the affordability of user devices will limit its accessibility.

In addition to these four archetypes, two countries emerge as unique cases:

— **China**: Over the last several years, China has poured huge amounts of capital into its fixed and cellular networks, building highly sophisticated and densified underlying communication infrastructure. The nation continues to roll out and enhance advanced technologies over this backbone at a faster rate than any other country. It is expected to invest another $145 billion in 5G over the next five years with the aim of offering it in all major cities and switching more than a quarter of Chinese mobile subscriptions to 5G networks by 2025.[95]

— **India**: India is digitizing faster than any trailing market. Previous MGI research estimated that the number of internet users could hit 800 million by 2023.[96] Although it is modernizing and expanding mobile networks, their performance metrics are likely to lag for most of the population, except a few key metro areas. Deployment of fixed networks will be challenging since low subscription prices limit commercial viability. It will likely take price increases or government action to spur buildout. For instance, the government has been supporting the BharatNet program, which is about halfway toward its goal of bringing high-speed broadband to India's 250,000 villages.[97]

The connectivity divides separating the four country groups are likely to persist, and even grow, over the next decade

The type and extent of connectivity infrastructure ultimately deployed will vary from one country to another, and even within the same country. While providers in pioneer markets are starting to roll out high-band 5G in select urban areas, they will most likely start with low- to mid-band 5G in many places, then upgrade the infrastructure as the market matures and demand increases. Providers in trailing countries will most likely invest in offering low- to mid-band 5G to the biggest share of the population they can manage. In each country, the revenue potential, the costs of labor and equipment, urbanization, and the provider's own financial capacity will determine the viability of investments—and result in different coverage rates.

The economics work for providers to cover some 80 percent of the world's population (approximately 7 billion people) with low- to mid-band 5G networks by 2030, although the level of quality will vary. We estimate that this expansion of coverage could come at a total cost of some $400 billion to $500 billion. This deployment will rely heavily on existing 4G infrastructure but would offer upgraded capabilities that can support most (but not all) use cases.

95 Yang Yang, "China to invest over 1T yuan in 5G tech by 2025," *China Daily,* July 31, 2019.
96 *Digital India: Technology to transform a connected nation,* McKinsey Global Institute, March 2019.
97 "BharatNet links 1.29 lakh panchayats: Ravi Shankar Prasad," *Economic Times,* December 2019.

Deploying a true high-band 5G network over the millimeter wave spectrum requires more tailored infrastructure—and greater investment. Connectivity providers would need to densify their radio access network, upgrade the 5G core network, and upgrade network operating systems to offer the full capabilities in terms of speed, latency, and device density. We estimate that they will need to invest $700 billion to $900 billion to bring this type of coverage to 25 percent of the global population. These networks are likely to be limited to select geographies for the foreseeable future.

In a number of countries, fiber networks have been built out with public subsidies where they were not economically viable for connectivity providers.[98] Over the next decade, the build-out of advanced fixed networks will still be limited by its own business case. Barring support from other public or private stakeholders, the world's fiber coverage should grow to around 50 to 55 percent of the population, up from today's coverage levels of 40 to 45 percent.

As a result of these differences across countries, the connectivity divide across segments could widen (Exhibit 15). The differences are stark when it comes to high-band 5G. Thanks to extensive existing radio access and backhaul infrastructure and providers with strong capital positions, up to 50 to 55 percent of the population in pioneer countries and China could have coverage by the end of the decade. By contrast, frontier networks might reach between 5 to 15 percent of the population in trailing markets and India.

On the fixed side of things, the story is quite different. Pioneer countries and China already enjoy a higher rate of fiber network coverage than the rest of the world, leaving little room for growth. Leaders are likely to post modest growth over the decade. But follower markets are starting with relatively low fiber coverage of less than 30 percent, and a significant number of unconnected areas are dense enough to create a solid business case for connectivity providers. We estimate that coverage in these markets could double as they pursue catch-up growth. Trailing markets and India are similarly starting with low coverage rates, even in dense areas, but they are unlikely to follow suit due to the limited revenue potential that is foreseeable today.[99] Fixed networks might only be available to about 10 percent of the population.

Even within individual countries, we see a rural-urban gap forming. Many rural areas will gain improved service but will not enjoy the same level of network performance as cities (Exhibit 16). By 2030, some 80 to 85 percent of urban dwellers worldwide—but almost none of the global population in rural areas—could have frontier connectivity coverage. This is even wider than the urban-rural gap in current LTE coverage.[100] The divide within trailing countries could be especially stark, reflecting differences in both prosperity and density between the urban and rural populations.

With the previous generation of networks, providers typically aimed for nationwide or near-nationwide coverage. But the high costs of building out 5G, combined with the projections for incremental revenue, means that they will have to take a more targeted approach.[101] Yet in certain dense urban areas with very high per capita data consumption, providers may find that the network efficiency benefits alone justify deployment as they cope with growing device density and data traffic. Many rural areas, however, simply do not have the density nor the business presence to support the capital investment that is needed; the cost per customer served is simply too high. Closing these divides would require the public sector, or other private investors to step in to support rural coverage to ensure more inclusive access.

98 *The Global Information Technology Report 2010-2011: Creating a fiber future: The regulatory challenge*, World Economic Forum, 2011.

99 By contrast, we do see significant potential for use cases enabled by intermediate connectivity. See *Digital India: Technology to transform a connected nation*, McKinsey Global Institute, March 2019.

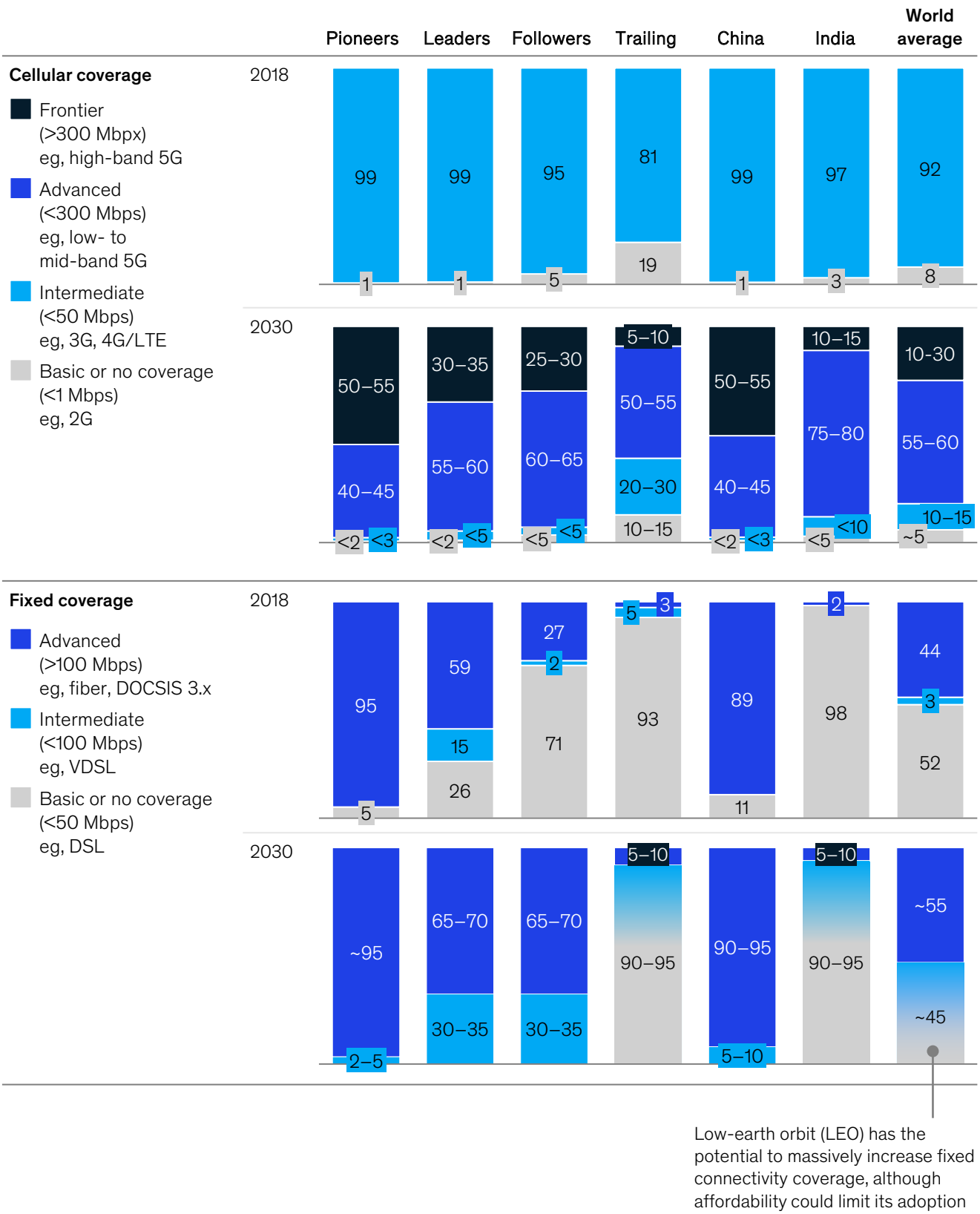
100 Long Term Evolution is a 4G wireless communications standard.

101 *Ericsson Mobility Report*, Ericsson, November 2019.

Exhibit 15

Connectivity divides between country archetypes are likely to widen.

% of population



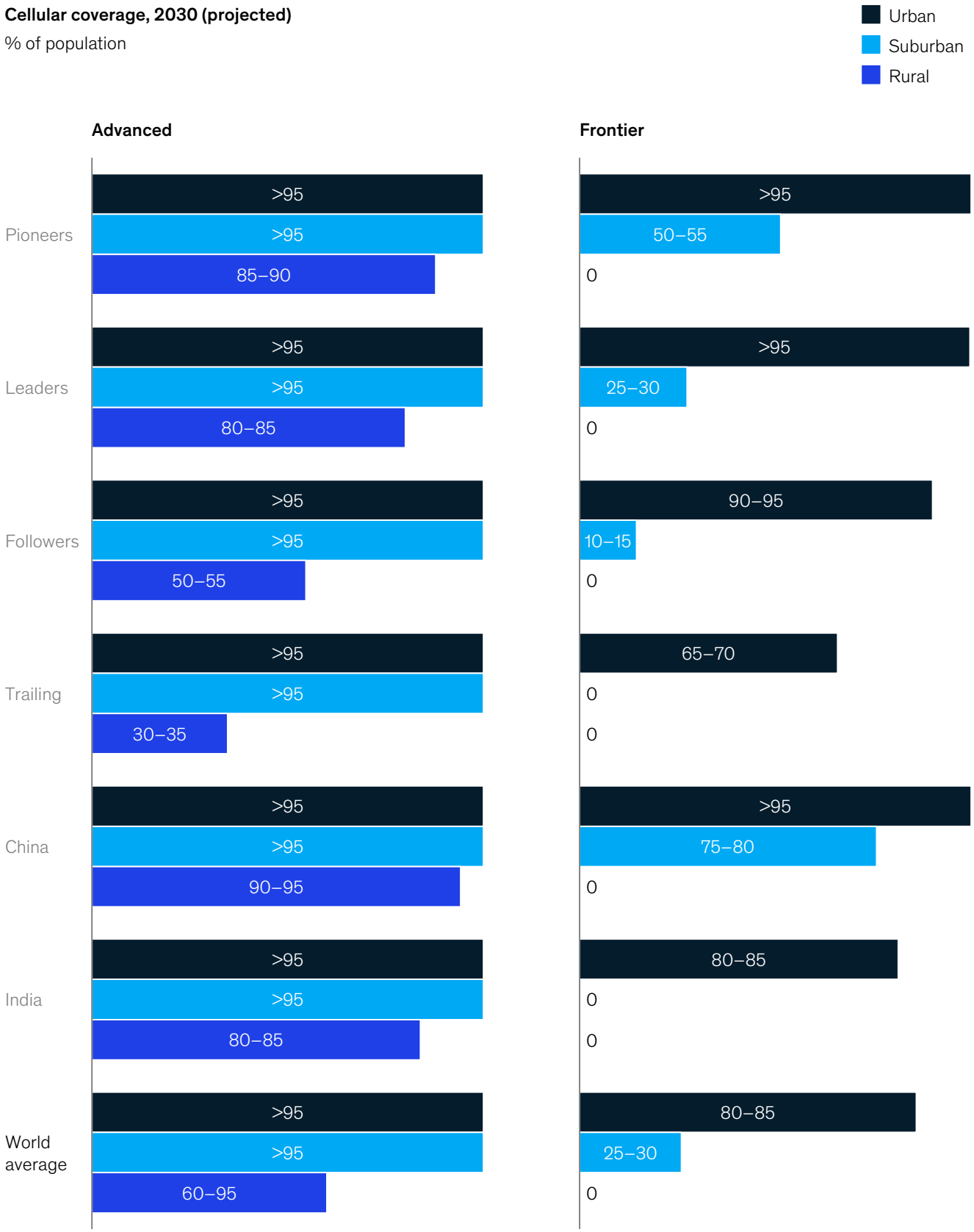
Note: Figures may not sum to 100% because of rounding.
Source: McKinsey Global Institute analysis of data from GSMA Intelligence; iDate; Analysys Mason; Ovum; *The Economist*; United Nations; World Bank; WCIS; National Census Bureaus; corporate annual reports and press releases

Exhibit 16

The challenging economics of deploying frontier cellular networks in remote areas will widen the urban-rural gap.

Cellular coverage, 2030 (projected)

% of population



Note: Figures may not sum to 100% because of rounding.

Source: McKinsey Global Institute analysis of data from GSMA Intelligence; iDate; Analysys Mason; Ovum; *The Economist*; UN; World Bank; World Cellular Information Service; national census bureaus; corporate annual reports and press releases

The distribution of economic value associated with use cases is likely to be uneven across country groups, thereby expanding economic gaps

The $1.2 trillion to $2 trillion of value at stake in the four commercial domains we studied will not be divided evenly across country archetypes (Exhibit 17). The countries at the forefront could capture a disproportionate share of the value, while trailing countries could fall further behind—and the distribution is especially skewed when it comes to frontier use cases.

Exhibit 17

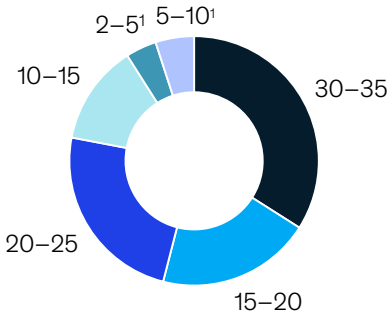
The value produced by use cases running on advanced and frontier connectivity could be distributed unevenly.

2030

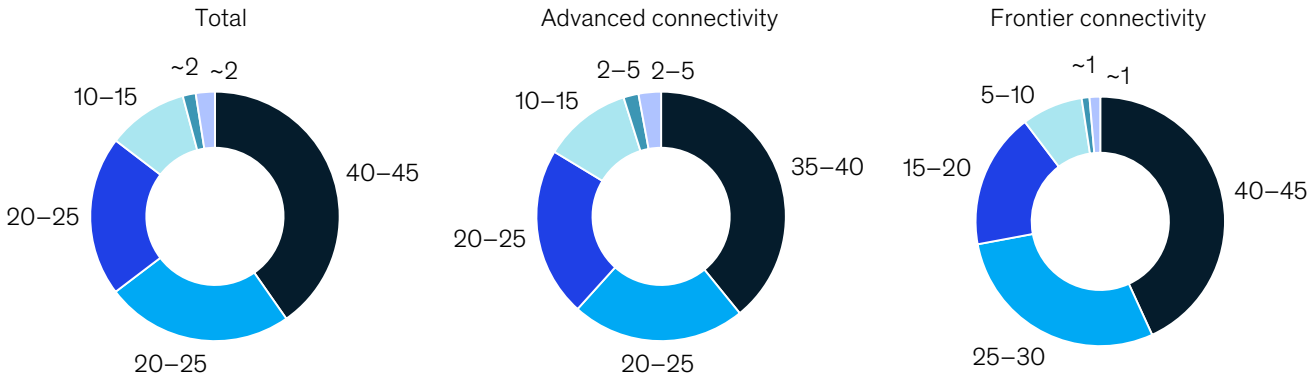
%

Pioneer | China | Leader | Follower | Trailing | India

Projected global GDP contribution by country archetype



Distribution of GDP impact of connectivity-enabled use cases



Note: Figures may not sum to 100% because of rounding.
1. The relatively low shares in India and trailing markets could be offset by a range of use cases enabled by the expansion of intermediate connectivity, as well as foundational digital identification infrastructure and digital payment systems.
Source: McKinsey Global Institute analysis of data from GSMA Intelligence; iDate; Analysys Mason; Ovum; *The Economist*; UN data; World Bank; World Cellular Information Service; IHS Markit Global Industry Service; national census bureaus

These differing outcomes stem from the expected availability of advanced and frontier connectivity. Looking at anticipated coverage rates across archetypes reveals a far more pronounced gap for frontier connectivity than for advanced. This division is even more significant when considering coverage in urban areas, since these areas ultimately contribute the largest share of GDP.

For advanced connectivity use cases, we estimate that pioneer markets and China will capture slightly more value than other archetypes, relative to their projected contribution to 2030 global GDP. At the other end of the spectrum, India and trailing markets are expected to capture a smaller share of value than their expected contribution to global GDP in 2030 would

indicate.[102] Leader and follower markets stand to capture economic benefits at a rate that is largely in line with the share of global GDP they produce. In terms of figures, we estimate that 60 to 65 percent of the value could go to pioneer markets and China, 20 to 25 percent to leader markets, 10 to 15 percent to followers, and just 5 percent to India and trailing countries. The share going to China and pioneers would exceed their weight in the global economy by 10 to 20 percent, while the share going to India and trailing markets would fall quite a bit below.

For frontier connectivity use cases, the dispersion of value is more striking. We estimate that 70 to 75 percent would go to China and pioneer markets, 15 to 20 percent to leaders, 5 to 10 percent to followers, and only 2 to 5 percent to India and trailing countries. China stands to capture an outsized share that could be 40 to 50 percent higher than its share of global GDP, while the share going to pioneer markets could be 20 to 30 percent higher. This mainly results from the fact that these nations are highly urban, with GDP concentrated in those urban areas. On top of that, China is already deploying new networks rapidly. However, the story is not as positive for the rest of the world. With lower urban concentration and more incremental gains in connectivity, leaders might capture a share that is 20 to 30 percent lower than the size of their economies would indicate, with followers punching at 30 to 40 percent below their weight. Trailing countries and India come in at 70 to 80 percent below their share of global GDP.

Bringing more of the world online could help narrow the connectivity gap and economic gap between country groups

Although mobile adoption has increased significantly over the past few years, some 40 percent of the global addressable population remains unconnected to 3G-capable networks or better. That means some 2.5 billion people are still offline.[103] Addressing this divide is an important issue for economic and human development. In fact, providing "universal and affordable access to the Internet in least developed countries" is one of the UN's Sustainable Development Goals.

Some 400 million people around the world, mainly in the rural areas of trailing countries, are not covered by any network and so have no access. But the absence of networks is not the only issue. Some 2 billion people are covered by networks but are not using the mobile internet due to other barriers. These include the affordability of devices and data plans, readiness (including illiteracy and lack of digital skills), and the relevance of online content.

Even without connectivity advances, demographic and economic shifts appear likely to draw a billion more people online by 2030. First, population growth alone, at current adoption rates, should add 400 million new mobile internet users.[104] Second, urbanization will likely bring 150 million currently unconnected rural inhabitants to urban areas with better job opportunities and better network coverage (although high birth rates in rural areas of developing countries will partly counter this trend).[105] Third, rising household incomes should enable 450 million people to afford devices or data plans for the first time (at current prices).[106] Finally, improvements in literacy and digital skills should equip 300 million people to go online.[107] Yet some people who meet these prerequisites will not feel the internet's pull, largely due to a lack of relevant content (particularly content in their own language).

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[102] It should be noted that significant value and GDP gains are possible in India and trailing markets from a range of use cases enabled by the expansion of intermediate connectivity, along with foundational digital identification infrastructure and digital payment systems. See *Digital India: Technology to transform a connected nation*, McKinsey Global Institute, March 2019; and *Digital identification: A key to inclusive growth*, McKinsey Global Institute, April 2019.

[103] We define the "unconnected" population as individuals over 11 years of age who do not use mobile internet (3G or later technology). Some of these individuals have access to voice networks, so they are sometimes referred to as "under connected" in the economic literature. But for our purposes, since this population has no data connectivity and no Internet access, they are effectively "unconnected"—particularly in the context of the advanced and frontier connectivity technologies that are the focus of this report.

[104] *World Population Prospects 2019,* United Nations Population Division.

[105] *World Urbanization Prospects: 2018 Revision,* United Nations Population Division.

[106] Based on data from Oxford Economics Ltd.

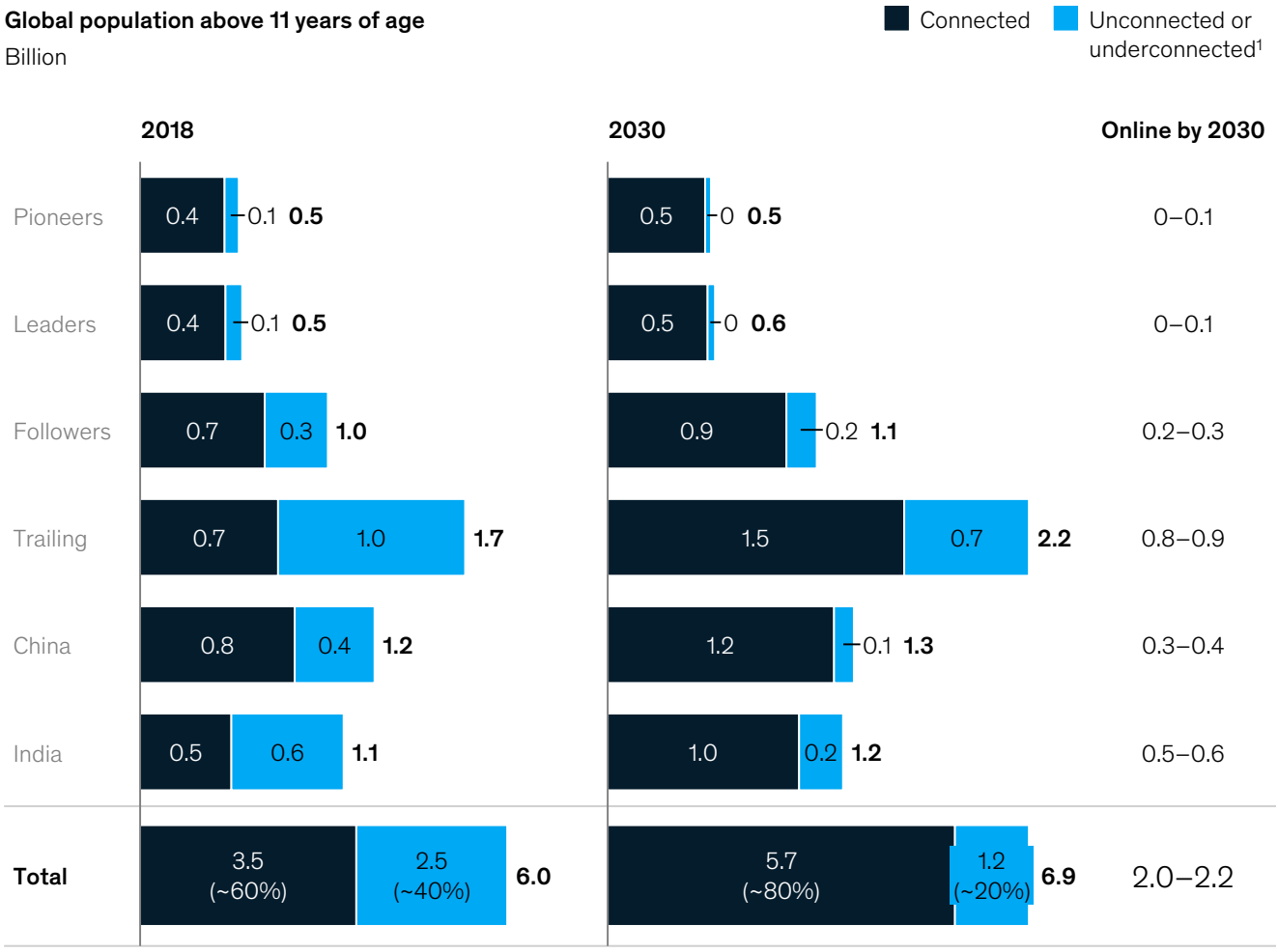
[107] Current and historical literacy rates from UNESCO data, combined with McKinsey projections for future literacy rates. GSMA Intelligence data on digital skills.

On top of the demographic and economic trends described above, another 800 million to 1 billion people could come online as a result of improving availability, affordability, and relevance. Network rollouts and upgrades, especially in the rural areas of trailing countries, are expected to shrink the coverage gap to only 4–6 percent of the global population. The affordability gap should shrink to affect only 6–14 percent of the population if the prices of the cheapest smartphones continue to fall and connectivity providers can offer cheaper entry-level data plans for low-income customers. Finally, local content and services will develop over time, enticing more people online to access them.

As a result of all these developments, the share of the global addressable population remaining offline should be reduced by half, falling from 40 percent today to 20 percent by 2030. Despite this progress, more than 300 million people, mostly in rural areas of trailing countries, could still lack network coverage (Exhibit 18). Furthermore, around 1 billion people could remain offline due to the persistence of the affordability, relevance, or readiness barriers discussed above.

Exhibit 18

The share of global population remaining unconnected or underconnected should be reduced by half, falling from 40 percent in 2018 to 20 percent in 2030.



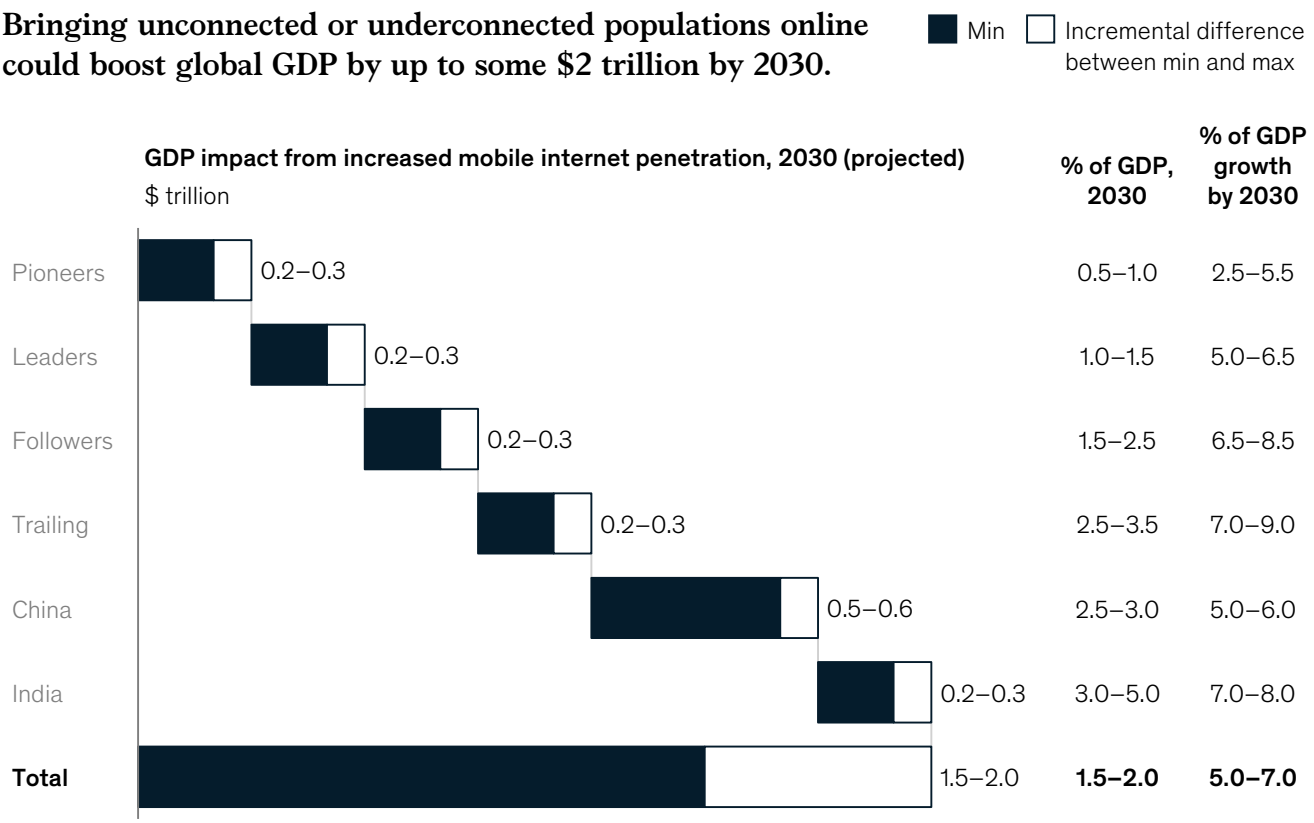
1. The underconnected population includes individuals who do not use mobile internet (3G or later technology).
Note: Figures may not sum to 100% because of rounding. Not to scale.

Source: McKinsey Global Institute analysis of data from GSMA Intelligence; IMF; IHS Markit Markit; UN; IDC; World Bank; Oxford Economics; Tariff; A4AI; ITU; eMarketer; Analysys Mason; expert interviews; and operator financial statements

Bringing more of the global population online could add some $1.5 trillion to $2 trillion to global GDP by 2030 through improved communication, broader social inclusion, and enhanced productivity across domains.[108] China is expected to be the biggest gainer in absolute terms, while trailing countries, follower countries, and India are expected to make the greatest relative gains (Exhibit 19).

Exhibit 19

Bringing unconnected or underconnected populations online could boost global GDP by up to some $2 trillion by 2030.



Note: Figures may not sum to 100% because of rounding.

Source: McKinsey Global Institute analysis of data from GSMA Intelligence; Analysys Mason; IMF; World Bank; UN data; Deloitte; Cisco; IHS Markit; and Ericsson

Connectivity providers face a tough road ahead

Gaining a better view of how connectivity might evolve over the next decade naturally requires a closer look at the providers that will put the world's new digital backbone in place. The telecom industry of yesterday, with high barriers to entry and few competitive challenges, is a thing of the past.[109] Disruption is coming from multiple angles, including the entry of new players and even price wars in some markets.

The rollout of advanced and especially frontier connectivity demands major investment—at a time when mature markets are saturated, competition is leading to price wars, and wireless plans are becoming commoditized.

Differences in the economics of each market will influence how and where providers decide to invest, as described in the previous chapter. From today through 2025, those in pioneer markets are projected to spend up to $1,000 per capita while those in trailing markets could invest only $20 to $30 per capita. Some of this gap is due to varying labor, land, and material costs, but much of it comes down to companies investing where they see higher revenue

[108] The World Bank's literature review of multiple cross-country and single-country studies finds a positive economic impact from the expansion of fixed broadband and mobile coverage. See Michael Minges, *Exploring the relationship between broadband and economic growth,* January 2015. For more on the channels through which digital inclusion spurs economic growth, see *World development report 2016: Digital dividends,* World Bank Group, 2016.

[109] For more on the strategic challenges facing providers, see "Are you ready for 5G?" McKinsey.com, February 2018.

potential and more favorable conditions for deployment. While providers in pioneer markets and China have already invested heavily in infrastructure and are well-positioned to build on their head start, those in the rest of the world will collectively need to find additional revenue sources to cover the costs of enhanced networks sustainably.

The ability of providers to shoulder heavy capital investment in the coming years depends not only on the opportunities but on their financial health (Exhibit 20). Those in leader markets (particularly in Europe) have experienced stagnant growth and increased price competition. From 2012 to 2018, revenues for the group as a whole fell by 14 percent in a period when capital investment increased by almost one third, leading to significant fall in free cash flow. This puts these companies in a tougher position as they contemplate the need to continue increasing capital investment by 6 percent annually over the coming five-year period.[110]

Providers in follower countries have posted stable revenues amidst increasing capital expenditure. But they have been able to capture operational efficiencies and make strong improvements in their cash flow.

Those in trailing countries and India had revenue growth of 43 percent and 8 percent, respectively, from 2012 to 2018. But their cash flow growth did not keep pace. Connectivity providers in India, in particular, face unique challenges. Some carriers have invested heavily in 4G and LTE infrastructure while cutting the price of their services dramatically. This has left the entire industry under pressure, with capital investment exceeding EBITDA in 2018.

Over the next five years, we expect to see providers in pioneer countries continue with steady increases in capital investment of around 1–3 percent annually (up to $1,000 per capita).[111] Those in pioneer countries and China have already undertaken major buildouts, and they should be carried by strong sales growth and operating cash flow.

In the future, markets that have already invested heavily in laying the infrastructure foundations necessary for advanced cellular connectivity will likely be able to maintain stable ratios of capital investment to earnings. But the rest of the world will face difficult choices as they strive to catch up while producing positive returns. Providers with "unhealthy" capital intensity have limited options to reverse these trends. Those in leader, follower and trailing markets are projecting limited additional growth, and as a result, they will have to find additional revenue streams or revisit pricing (Exhibit 21).

Some of that additional revenue can come from connecting currently offline populations, as discussed earlier. Providers in trailing markets and India can substantially expand their subscriber bases, but they will have to overcome their current monetization issues to gain significant revenue from these new consumers.

One illuminating exercise to show the disparity in provider outlooks across markets is to translate revenue required to fund investments into relative growth rates and compare them to projected revenues over the next decade in different markets. Providers in leader markets would need to reverse their negative to zero projected growth and achieve at least a 1 to 1.5 percent positive annual growth rate. These figures contain a world of differences, however. The leader countries most affected by price competition would need to achieve at least a 3 to 4 percent annual growth rate. Those in follower markets must more than double their projected annual growth rates from roughly 2 to 5 percent to make capital investments sustainable. Providers in trailing markets would need to boost growth from 1 to 2 percent to 2.5 percent. In India, it will take growth of 5.5 to 6 percent, well above the currently projected 4.5 percent. These growth requirements would cover only expected increases in capital investment, not spectrum licensing and other expected operating costs.

[110] Based on McKinsey Global Institute analysis of GSMA Intelligence data.
[111] Ibid.

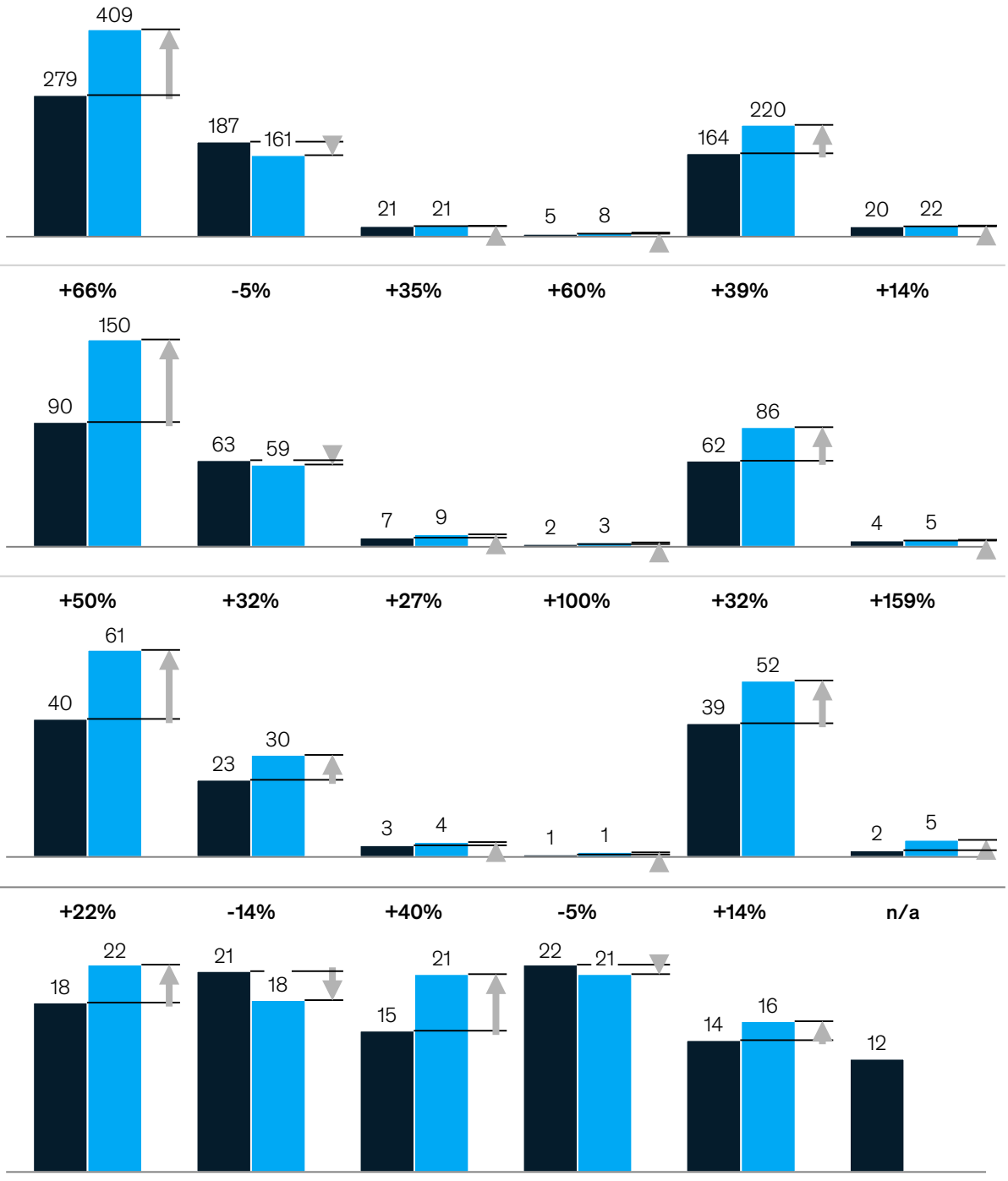
Exhibit 20

The financial position of connectivity providers varies sharply across geographies.

Sum for top 3–5 operators, 2012 and 2018

Annual reports ■ 2011/12 ■ 2017/18

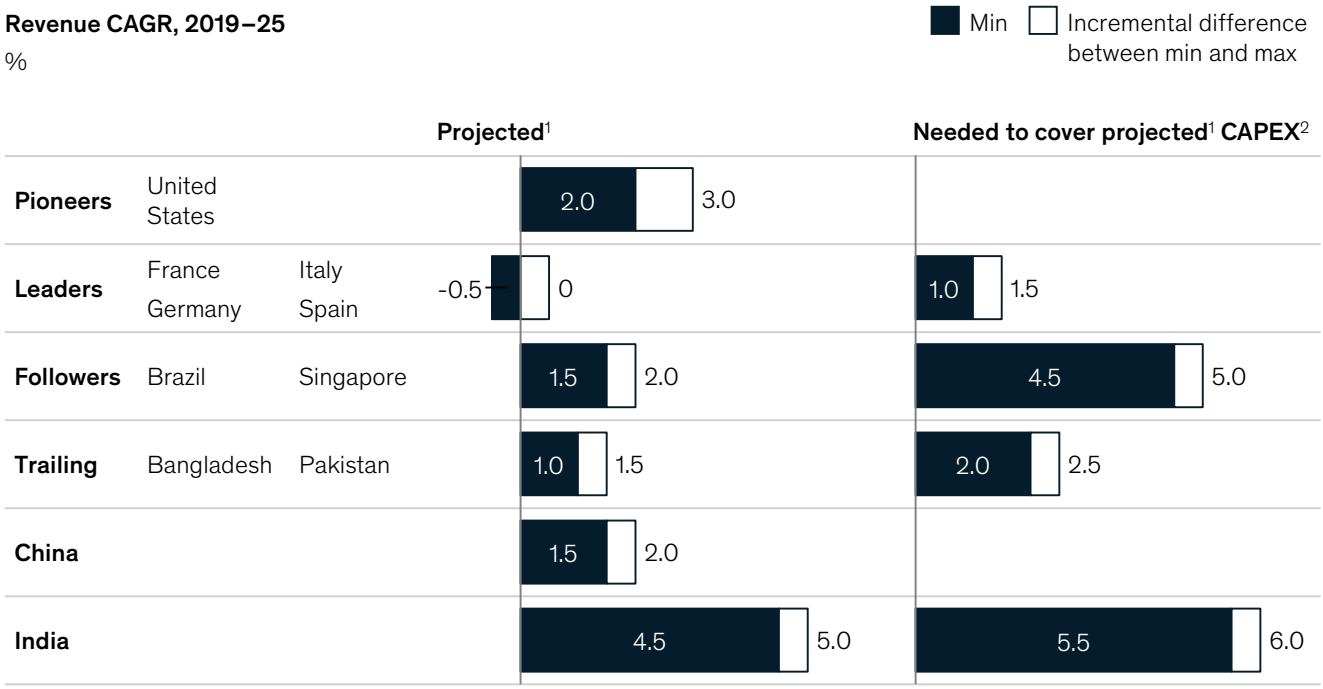
	Pioneers	Leaders	Followers	Trailing	China	India
Analyzed cases	United States	France Germany Italy Spain	Brazil Singapore	Bangladesh Pakistan		
Revenue $ billion	**+46%**	**-14%**	**+2%**	**+43%**	**+34%**	**+8%**
EBITDA $ billion	**+66%**	**-5%**	**+35%**	**+60%**	**+39%**	**+14%**
CAPEX $ billion	**+50%**	**+32%**	**+27%**	**+100%**	**+32%**	**+159%**
Operating cash flow ratio Cash flow % of revenue	**+22%**	**-14%**	**+40%**	**-5%**	**+14%**	**n/a**



Note: Not to scale. Figures may not sum to 100% because of rounding.
Source: GSMA Intelligence; provider financial statements; McKinsey Global Institute analysis

Exhibit 21

Connectivity providers in most markets will need more than organic growth to support the capital investment they need to undertake.



1. Estimated from GSMA Intelligence data.
2. Maintaining stable CAPEX/revenue ratio.
Source: McKinsey Global Institute analysis of data from GSMA Intelligence; provider financial statements

6. Questions for the future

Our research to date has confirmed the value of connectivity, identified specific use cases and barriers, and modeled how connectivity is likely to evolve across regions. But the outlines of this new connected world are still coming into focus, and many uncertainties remain. This is a complex transformation with many moving parts.

This discussion paper represents our initial exploration into how connectivity will affect individual industries and broader economies. A number of issues merit further exploration, both on the supply side and within additional domains beyond the ones covered here. Some of these questions are posed below—and we hope to tackle some of them as part of our ongoing research.

Can connectivity providers solve the monetization puzzle?

The first set of questions is related to connectivity providers and how they can capture more of the economic value from the infrastructure they provide.

As they seek to build out and upgrade networks, these companies face challenges on the financial, regulatory, competitive, and business model fronts. The need to stay current could leave many in a difficult situation as they face the realities of their financial and market positions. How they choose to approach these challenges will determine how the new world of connectivity evolves.

Can they adjust their pricing strategies and add adjacent specialized services while staying within their traditional value chain? What is the potential for network slicing (offering virtual pieces of their network with different technical specifications), service-level pricing (to monetize ultra-low latency), or network sharing (forming partnerships to share the fixed costs of deployment with other providers)?

How can providers partner with businesses in other domains to create viable long-term strategies? Such partnerships are becoming more important in other domains that are also facing heavy capital investment needs, including those analyzed in this research. Over time, could providers claim a bigger partnership role in developing innovations such as connected vehicles, remote healthcare, or the Internet of Things?

What will the connectivity ecosystem look like in a decade's time?

A second set of questions revolves around what types of new players might become connectivity providers. As noted in Chapter 5, telecom operators may be joined by satellites, tower and infrastructure companies, and tech companies.

How likely is it that today's traditional telecom operators will continue to provide the backbone of connectivity architecture for years to come? What about in the "last mile" of connectivity services? As commercial demand for industrial 5G use cases grows, for example, industrial players and hardware providers may consider building out the "last mile" services in the form of private networks.

Similarly, other technology companies that play in the same ecosystems and offer adjacent services may also consider expanding into connectivity services. Some internet companies have explored moving into this space (most notably Google, which has launched fixed, cellular, and ISP offerings such as Google Fiber, Google Fi, and Loon).[112] Other technology players are eyeing opportunities in IoT connectivity (such as Amazon Sidewalk).[113] How different will the provider ecosystem look across different regions by 2030?

How might the technical architecture of different domains evolve?

Beyond infrastructure implications for connectivity providers, the technical architecture of specific domains is evolving. Enhanced connectivity may open opportunities to rethink where and how computing happens, especially when it is combined with advances in computing (such as cloud, edge, and quantum computing), device and sensor efficiency, storage, and software design. Connectivity providers and technology companies alike are already hurrying to identify potential new offerings through partnerships, as evidenced by Amazon and Verizon's recent 5G Edge computing partnership.[114] These changes could have meaningful implications for the full technical stack of companies and across entire domains.

To what extent do we expect to see meaningful change within the existing architecture? In which domains will the biggest changes occur?

These questions and more will provoke interesting discussions about the future of infrastructure, application development, the broader technology product and service provider industries, and the capabilities that will drive the technology sector of the next decade.

Meet the new consumer, same as the old consumer?

Another set of questions relates to consumers. Will the same issues of monetization and misaligned incentives that exist in advanced markets be repeated with the new consumers coming online for the first time across the developing world? What new economic value will these consumers unlock, and what opportunities will be created for businesses?

Additional questions center around those high-use consumers who already drive the majority of the world's data consumption and will likely continue to do so by decade's end. We expect to see massive growth in online viewers and also more time spent viewing per user. Given consumers' seemingly insatiable demand for higher-quality video and more sophisticated gaming applications, can providers convert this demand to value through advanced and frontier connectivity? Much of the consumer demand today is highly skewed, with 20 percent of consumers being "power users" who are responsible for the majority of the usage. Will new consumer applications, including augmented and virtual reality, change this pattern or skew it even further? The answer may depend on the extent to which consumer applications go beyond media and entertainment into other domains such as education and services.

What kind of potential and barriers exist in other parts of the economy?

A related area for further research centers around the value and barriers in other commercial domains. Beyond the four analyzed in this report, we identified another 13 commercial domains that also hold significant potential, ranging from logistics and services to mining and agriculture.

[112] Paresh Dave, "Google internet balloon spinoff Loon still looking for its wings," Reuters, June 30, 2019.
[113] Frederic Lardinois, "Amazon Sidewalk is a new long-range wireless network for your stuff," TechCrunch, September 25, 2019.
[114] "AWS and Verizon team up to deliver 5G Edge cloud computing," Amazon News Center, December 2019.

How much more economic value can they generate? How different are their use cases from the ones considered in this research, and can most of them similarly be executed using currently available technologies?

Across the board, we observe that the adoption of use cases has been largely localized or limited to pilots, with little to no broad, at-scale adoption. This suggests that some combination of hurdles may be to blame for this lack of momentum. Beyond the barriers identified in this research, do other domains have additional, specific issues due to their market dynamics, incentives, or regulations?

What is the role of policy?

Lastly, the role policy makers will take in shaping the connected world of the future remains unclear.

At the global level, for instance, what effect will recent technology "decoupling" trends between the United States, China, and other countries have on supply chains, technology standards, and end-user adoption?

At the country level, this research has identified four archetypes (plus China and India) that we expect will evolve differently due to differences in demand, infrastructure, and economic viability. But government action can change these dynamics in ways that are difficult to foresee. To date, governments around the world have taken markedly different approaches in facilitating the expansion and evolution of connectivity. In some markets, governments have played a very hands-on role through direct investment and subsidies for connectivity providers. Some are investing heavily in R&D. Others are taking a more hands-off role, simply facilitating the broader connectivity market through actions like spectrum auctions.

In addition to these levers, regulations on topics such as spectrum sharing and power density will have major implications for where, when, and how the value of enhanced connectivity will be realized.

Technical appendix

1. Estimating data demand
2. Estimating the GDP impact of use cases
3. Estimating the value associated with use cases in mobility
4. Estimating the value associated with use cases in healthcare
5. Estimating the value associated with use cases in manufacturing
6. Estimating the value associated with use cases in retail
7. Defining country archetypes
8. Estimating the cost of deployment and future coverage
9. Assessing connectivity providers' capacity for investment
10. Estimating the share of the population that will remain offline by 2030

1. Estimating data demand

To consider how internet data traffic is likely to grow through 2030, we use projected growth rates through 2022 from the *Cisco Visual Networking Index* and then extrapolate for the remaining years through 2030. We validated our growth assumptions, finding them highly similar to estimates from other sources such as the *Ovum Network Traffic Forecast (2018-2023).*

We take a similar approach to determine how data traffic is likely to be split across various dimensions:

— To determine projected growth for each country archetype, we use country-level and regional growth rates through 2022 from the *Cisco Visual Networking Index,* combine results using our archetype classification, and extrapolate for the remaining years until 2030 using the compound annual growth rate from 2017 to 2022, excluding the effect of growth in the number of internet users.

— To project the split between network types, we use growth rates from the *Cisco Visual Networking Index* through 2022 and extrapolate through 2030.

— To project the split between different types of applications (such as online video and gaming), we use growth rates from the *Cisco Visual Networking Index* through 2022, extrapolate the development of each application type through 2030, and normalize by the growth of total internet data traffic.

— To project the split between different types of devices (such as smartphones and machine-to-machine devices), we use growth rates from the *Cisco Visual Networking Index* through 2022, extrapolate the development of each device type until 2030, and normalize by the growth of total internet data traffic.

2. Estimating the GDP impact of use cases

We calculate the GDP impact of the use cases in four domains (mobility, healthcare, manufacturing, and retail), as described below, then extrapolate to the rest of the economy while differentiating between highly digitized and less digitized industries.

In addition to building on our modeling of impact in these four domains, we rely on the following data sources:

— We use IHS Markit's Global Industry Service data for GDP and gross output projections over the period spanning 2018 to 2030, by industry. This covers 75 countries that collectively account for approximately 93 percent of the world's GDP.

— We use the International Labor Organization's as source for employment data, by industry and by occupation segment. This includes 10 occupation segments (e.g., managers, clerical support workers, etc.) and covers only 64 countries; therefore, it is primarily used to inform the split within each industry between occupational segments.

To calculate the GDP impact from enhanced connectivity within an industry, we differentiate between three types of use cases:

— For use cases that create new revenue opportunities, we derive the related GDP impact in 2030 by multiplying the sized revenue in 2030 by the industry's ratio of gross output minus cost base to gross output in 2030, as follows:

$$GDP\ impact = Revenue\ Generation \times \frac{Ind.\,Gross\ Output - Ind.\,Cost\ Base\ GDP}{Industry\ Gross\ Output}$$

— For use cases that create cost savings, we consider the related GDP impact in 2030 to be equal to the sized cost saving value in 2030.

— For use cases involving a spending reduction in industries such as healthcare (e.g., public and out-of-pocket healthcare spending), we derive the related GDP impact by multiplying the sized savings in 2030 by the industry's ratio of GDP to gross output in 2030, as follows:

$$GDP\ impact = Spending\ saving \times \frac{Industry\ GDP}{Industry\ Gross\ Output}$$

For each use case, we also identify the main occupation involved in creating value. This allows us to determine the contribution of each employment segment to the GDP impact from advanced connectivity in the four industries profiled in detail. We then apply this extrapolation to other industries, comparing the ratio of each occupational segment in the employment base of the sized industries to that of the remaining industries.

The extrapolation also accounts for the relative level of digitization of other industries as compared with the sized industries. The remaining industries are split into two sets: those with a high Digitization Index score and those with a lower score.[115] The impact that advanced connectivity brings to each of these two sets of industries is proportional to the ratio of their Digitization Index score to that of the sized industries.

The distribution of the GDP impact by type of connectivity (advanced and frontier) results from a bottom-up classification of the four industries' use cases. This is then distributed by country archetype based on anticipated coverage rates and the concentration of urban population.

[115] *Digital America: A tale of the haves and have-mores,* McKinsey Global Institute, December 2015; and *Digital Europe: Pushing the frontier, capturing the benefits,* McKinsey Global Institute, June 2016.

3. Estimating the value associated with use cases in mobility

We estimate the revenue opportunities and cost savings that could be generated by a defined set of use cases relating to mobility, then extrapolate to arrive at the value at stake in the broader industry.

We rely on a number of key sources. For penetration rates and the number of cars in operation, we use projections from the McKinsey Center for Future Mobility.[116] For the individual use cases, we conducted interviews with industry experts and relied on data from sources including Statista, the American Automobile Association, and the US Department of Transportation.

For each use case, we define the revenue or cost savings stemming from either advanced or frontier connectivity on a yearly, per-car basis. We consider five use cases:

— **Infotainment:** We estimate potential subscription prices in audio, video, and gaming for both standard streaming and advanced services.

— **Predictive maintenance:** We estimate the unit revenue arising from the ability to monitor a vehicle's systems and send it to a preferred service provider when it needs maintenance. For such systems running on advanced connectivity, we further calculate the potential cost reduction for preemptively avoiding major breakdowns and smooth it over the life-cycle of the vehicle to get a yearly unit price.

— **Connected parking:** We estimate the revenue going to parking operators from recommendations through vehicle software. For frontier connectivity, we further expand the revenue pool with the potential income from car-pooling services.

— **Vehicle-to-vehicle warning systems:** We calculate the per-car cost reduction from avoiding hazards such as potholes and black-ice patches and the corresponding savings on maintenance and repair.

— **Connected surroundings:** We calculate the potential for improved navigation services based on the input from connected infrastructure and the device revenue from automatic road pricing systems.

For each use case, we interviewed industry experts to vet our assumptions and arrive at a realistic range of "take rates." We combined this with unit prices and the market penetration of each level of connected vehicle (basic, intermediate, and advanced) projected to be on the road in 2030.

To extrapolate across the broader industry, we used a McKinsey database covering more than 80 connectivity use cases. We scaled up by assuming that the use cases above are the five most valuable and then using the ratio of the top five to the total value pool from the 2016 *Car Data Monetization* publication. We further corrected for the larger size of the new use case catalog to ensure that we cover new applications of connectivity technology appearing in the past three years.

[116] See "The trends transforming mobility's future," *McKinsey Quarterly,* March 2019.

4. Estimating the value associated with use cases in healthcare

We estimate the global efficiency potential from 10 specific healthcare use cases enabled by various levels of connectivity. Our analysis relies on previous research conducted by McKinsey's Healthcare practice and the McKinsey Global Institute, as well as interviews with digital and healthcare experts.

For each use case, we define how the adoption levels of advanced and frontier connectivity vary across country archetypes. We forecast what could be achieved across base and stretch scenarios based on previously defined potential for digital solutions from the *Digitizing healthcare* model.[117] We apply the potential to projected levels of healthcare spending based on an MGI model that forms the basis of an upcoming report titled *The health of nations.*

We look at the most value-adding use cases in detail:

— **Remote patient monitoring:** We determine what value can be created by using advanced remote monitoring solutions for patients with chronic diseases, in terms of avoiding or reducing hospitalizations and minimizing primary care and specialist in-person visits.

— **Decision support solutions:** We estimate the savings associated with accelerated diagnoses, the prevention of errors and complications, identifying the most effective treatment protocols, and offering more personalized treatment plans.

— **Integrated command center**: We identify the efficiency opportunities associated with improved patient flows, optimal workforce scheduling, and optimized inventory and bed management.

5. Estimating the value associated with use cases in manufacturing

We analyze five specific use cases running on advanced and frontier connectivity in manufacturing industry to estimate the additional value they can create.

Our analysis relies on IHS Global Industry Service data for market size estimates and on the MPI Group manufacturing benchmark for cost base estimates. We also conducted interviews with industry experts and used previous McKinsey analyses to estimate the value unlocked by each use case.

— **Automated guided vehicles (AGVs):** We determine the share of warehouse tasks related to moving parcels and pallets that currently require human intervention but could be performed by fully autonomous AGVs.

— **3-D bin picking:** We estimate the share of labor dedicated to the preparation of parts on production line conveyors that can be streamlined with advanced robotics and computer vision.

— **System-wide real-time process control:** We determine the potential for quality improvements associated with the implementation of real-time process control systems based on the current average cost of downtime and defects in the manufacturing industry.

— **Augmented reality:** We estimate the productivity improvement resulting from the use of augmented reality in R&D, production, and logistics based on the current average labor cost associated to these three activities.

[117] "Digitizing healthcare: Opportunities for Germany," McKinsey.com, October 2018.

— **Vision quality checks:** We assess the baseline and the potential for improvement in the earlier detection of defects and the productivity gains resulting from the implementation of automated visual inspection on the production line.

For each of these use cases, we take the total potential value identified as described above, then apply "take rates," accounting for the level of applicability by sub-industry and across advanced and emerging economies. We conducted interviews with industry experts to vet our assumptions and build these rates, which, when applied to the potential maximum savings identified for each use case, gave us the estimated cost savings achievable.

6. Estimating the value associated with use cases in retail

We analyze ten specific use cases in the retail industry to estimate the revenue and / or cost savings they could produce, running on either advanced or frontier connectivity. Our analysis relies on Euromonitor and Forrester data for market size projections by channel and category as well as interviews with industry experts and previous MGI research.

— **Next-generation warehouse management:** We assessed three key activities (receiving, put-away, and picking) and determined for each how much time could be saved if products, boxes, and pallets were equipped with trackers for automatic scanning and location.

— **Real-time visibility during transportation:** We determined how much of the total cost of goods sold is lost during inbound transportation from manufacturer to distribution center, identified the main root causes of loss, and determined what share these losses could be reduced with tracking systems at different points in the transportation journey.

— **Out-of-stock mitigation**: We identified the current weighted average in-stock rate across retailers, then determined the room for improvement vs. best-in-class players using automated tracking systems. Based on this delta, we estimated how much additional revenue could be captured.

— **Shrinkage reduction**: We identified the average shrinkage rate across retailers, the main root causes (e.g., theft), and the total value of goods lost. We then determined how much of this could be reduced with advanced tracking systems and computer vision systems and calculated the savings.

— **On-shelf inventory tracking**: We identify the share of labor cost associated with in-store inventory management and how much of this time is dedicated to auditing in particular. Then we determined how much of this time could be reduced with tracking systems, on-shelf sensors, and computer vision to estimate the associated cost savings.

— **Optimizing working capital:** Using a weighted average cost of capital, we estimate the cost keeping inventory. Then we determined the potential reduce in inventory costs that could be realized with end-to-end product visibility enabling more accurate forecasts to size the cost savings.

— **Optimizing check-out:** We identified the average labor time spent on cashier activities and then identified how much could be reduced by connectivity-enabled solutions such as computer vision paired with automatic payment systems.

— **Next-generation in-store merchandising:** We identified how much time is spent in stores on directing customers and estimated how much could be replaced with connectivity-enabled systems and interfaces to calculate labor cost savings.

— **Real-time personalized promotions:** Based on previous research and category analyses, we estimated the potential sales increase that could be generated by real-time personalized promotions utilizing geo-fencing push notifications, computer vision with face recognition, and other connectivity-enabled solutions.[118]

— **In-store personalized recommendations:** Based on previous research and category analyses, we estimated the potential sales increase that could be generated by real-time personalized recommendations using advanced analytics, customer data, computer vision, and connected interfaces.

For each of these use cases, we then interviewed industry experts to vet our assumptions and define a "take rate," including the applicability in urban and rural areas of both developed and emerging countries (based on their expected future share of retail sales) as well as the applicability of each use case by category (based on that category's expected share of retail sales). Each use case has two take rates: one for solutions running on advanced connectivity, and one for solutions that require frontier connectivity. Checkout optimization, for example, can unlock more value when run on frontier connectivity, but it has a lower take rate due to implementation and capital constraints.

7. Defining country archetypes

We sort countries into four distinct groups based on where they stand in the connectivity continuum and their likely trajectory in the decade ahead. We consider factors including the average revenue per user, level of data usage, the quality and extent of existing telecom infrastructure, urban density, and market dynamics including regulation and competition. Our analysis relies on the following sources:

— Average revenue per user: GSMA Intelligence for cellular, Analysys Mason for fiber

— Share of urban vs. rural population and land size: World Development Indicators, World Bank

— Current cellular coverage levels by technology (e.g., 3G, 4G): GSMA Intelligence

— Cellular data traffic volumes: Analysys Mason

— Current fixed coverage levels by technology (e.g., fiber, DOCSIS 3.0): IDATE DigiWorld, Analysys Mason

— GDP per capita: World Bank

Within each group, we have singled out representative countries to analyze in more detail in our calculations for deployment, demand, adoption, GDP impact, and value distribution. The in-depth results for these sample countries are then extrapolated to the broader group.

We define four categories: pioneers (with Japan and the United States as the representative countries chosen for more detailed analysis), leaders (with Canada, France, Germany, and Thailand as representative countries), followers (Brazil, Poland, and Turkey), and trailing markets (with Pakistan and Nigeria as representative countries). Exhibit A1 offers a broader list of the countries that fall within each archetype.

In addition, China and India are treated as unique cases.

[118] *The Internet of Things: Mapping the value beyond the hype,* McKinsey Global Institute, July 2015.

Exhibit A1

We analyzed key drivers of 2030 connectivity maturity to classify countries into four different archetypes.

Not exhaustive

Low High

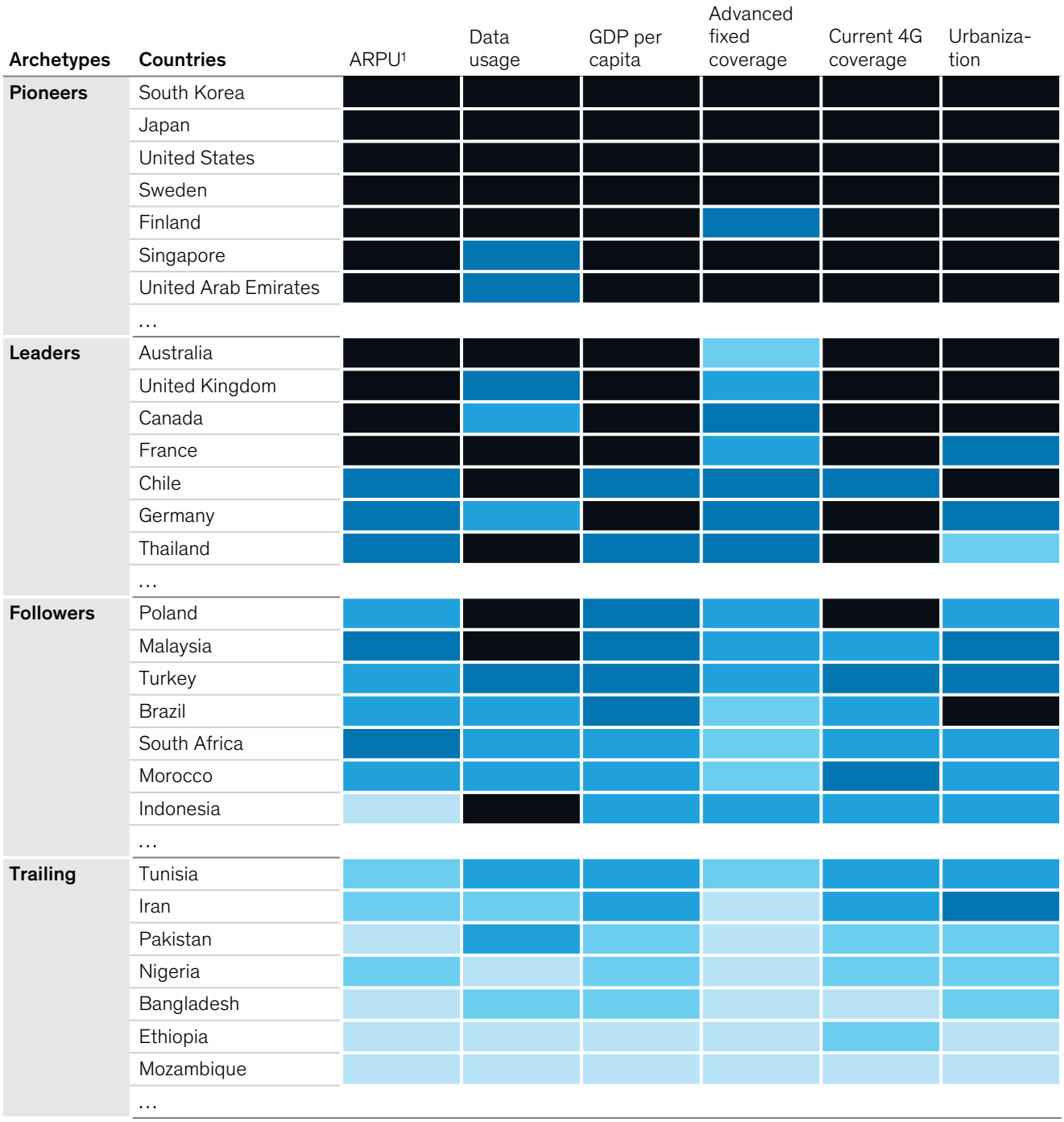
Our model evaluates countries against key connectivity drivers such as revenue, cost, competition, regulation, and spectrum availability (selected drivers illustrated below)

→

We clustered countries into 4 archetypes: Pioneers, Leaders, Followers, and Trailing (selected countries illustrated below)

→

We used supervised machine learning of advanced connectivity metrics to cluster countries by their projected connectivity development over the next 10 years



Note: Pioneers currently represent ~590 million people and ~$30 trillion in GDP; Leaders, ~600 million people and ~$20 trillion in GDP; Followers, ~1.2 billion people and ~$10 trillion in GDP; Trailing, ~2.3 billion people and $5 trillion in GDP. China and India considered separately.

1. ARPU = average revenue per user.

Source: McKinsey Global Institute analysis of data from GSMA Intelligence, Analysys Mason, IDATE DigiWorld, and the World Bank

8. Estimating the cost of deployment and future coverage

We calculate the cost of deploying advanced and frontier connectivity and the coverage rates likely to be achieved by 2030 for both fixed and cellular. Our global estimates are derived by considering representative countries within four archetypes (as described above), then extrapolating the results to the broader set of countries within that group. China and India are considered separately. The extrapolation is based on the cost of connectivity deployment per capita estimated for representative countries in urban, suburban, and rural areas, either fixed or cellular. This cost is then multiplied by the total archetype population in urban, suburban, and rural areas.

It is important to note that our projected coverage rates are based on determining economically viable operator investments. It excludes any potential investments from other private or social investors and any public support.

Our analysis relies on the following data sources:

— Population forecasts by country from the United Nations

— Share of urban vs. rural population and land size from the World Bank's *World Development Indicators*

— Labor rates from The Economist Intelligence Unit

— Current cellular coverage levels by technology (e.g., 3G, 4G) from GSMA Intelligence

— Current fixed coverage levels by technology (e.g., fiber, DOCSIS 3.0) from IDATE and Analysys Mason

— Existing number of cellular sites from OVUM's World Cellular Information Service

— 5G penetration forecasts by country (GSMA Intelligence data)

— Cellular data traffic volumes from Analysys Mason

— Average revenue per user from GSMA Intelligence for cellular, Analysys Mason for fiber

— Cellular and fixed capital expenditure projections from OVUM, GSMA Intelligence, and Analysys Mason

For fixed coverage, our calculation is based on fiber deployment costs by household, both in terms of labor and equipment, and the population to be covered in each country.

— We account for the variations between countries in labor costs by using The Economist Business Intelligence Unit data

— We account for variations between countries in equipment costs by attributing an equipment index to each country estimated by a panel of industry and geography experts

— Our calculation differentiates the cost of covering urban, suburban, and rural households, which vary due to household density and deployment distances.

— Once the total required investment is calculated, we consider the maximum coverage level beyond which deployment is no longer economically viable for operators. This threshold is expressed in terms of minimum household density. It is based on the expected average revenue per user from fiber and the lifetime of fiber infrastructure as well as the weighted average cost of capital and EBITDA margins for local operators. This minimum density

level is then converted into the percentage of households that are economically viable to cover.

— Finally, we model capital expenditure through 2030, considering the capital expenditure projections for fixed connectivity from OVUM and the share of the capital expenditure that is expected to be allocated to advanced connectivity (estimated by interviews with industry experts). We assume that connectivity providers will deploy first in urban centers, followed by suburban and then rural areas.

For cellular coverage, we similarly calculate the total investment in radio access networks required to achieve full advanced connectivity. This is defined as the level at which the entire population, in the inhabited land to have geographic radio access network coverage with the demand for data traffic fully met. The data traffic criteria is based on the average data consumption per capita in each country and a ratio of average to peak to account for variations in data traffic. To determine the required investment, we consider the following for both advanced and frontier connectivity rollout:

— The labor and equipment costs include those to install new cell sites and cell towers and to connect them with fiber backhaul.

— As with fixed coverage, our calculation differentiates the cost of covering urban, suburban, and rural households, which vary due to population density.

— We calculate the number of cell sites and cell towers needed to offer the full coverage in urban, suburban, and rural areas, taking into account the data-carrying capacity and range of cell sites. Both of these parameters depend on the connectivity level deployed and spectrum used. The use of millimeter wave for high-band 5G results in much lower cell site range and data-carrying capacity than mid-range 5G. In addition, we factor for variations in these ranges depending on whether the infrastructure is rolled out in urban, suburban or rural environments. As for the number of towers deployed, we take into account the tower-sharing practices between different operators, with the percentage of shared towers estimated by a panel of industry and geography experts.

— Once the total required investment in radio access networks is calculated, we determine the maximum coverage level beyond which the deployment is no longer economically viable. This threshold is expressed in terms of minimum population density. It is based on the expected average revenue per user and the lifetime of cellular infrastructure, as well as the weighted average cost of capital and EBITDA margins for local operators. This minimum density level is then converted into the percentage of population that is economically viable to cover.

— In the case of frontier connectivity (high-band 5G) deployment, we also modeled the investment needed to upgrade the core network, operating support systems, and business support systems. Our model incorporates data from Analysys Mason for 2020-25, which we have extrapolated to 2030.

— Finally, we model capital expenditure through 2030, considering the yearly capital expenditure projections for cellular connectivity providers and the share of that to be dedicated to building the backhaul and radio access network. This provides the yearly investment pool available for deploying cellular networks. To account for the new generation's maturity in each market, we then index the share of that yearly pool to be allocated to 5G networks to the future penetration of 5G devices.

— We assume that connectivity providers will start by offering advanced coverage, before deploying the more sophisticated frontier coverage. Also, we assume that connectivity providers will prioritize network rollout based on density; they will therefore cover urban centers first, then suburban areas, then rural areas.

9. Assessing connectivity providers' future capacity for investment

We assess the prior financial performance of connectivity providers in selected countries and estimate their future ratio of capital expenditure needs to expected revenue. In markets where that ratio exceeds 15 to 20 percent (and therefore is likely unsustainable), we then calculate the additional revenue needed to sustain this capital expenditure.

This analysis relies on two main data sources:

— For individual operators, we use the top three to five operators by revenue in each of the representative countries in our archetypes (described above in section 7). We examine their financial statements from annual reports to form a dataset of performance from 2012 to 2018. This covers some 95 percent of the market in these countries.

— For country-level data and forecasts, we use collected information on CAPEX and revenue projections from GMSA Intelligence.

To identify and size revenue gaps, we divide EBITDA by revenues for each country in 2017–18 and apply these to total revenue income in 2018. We then use capital expenditure projections from GSMA Intelligence to determine how the ratio of capital expenditure to revenue varies. To obtain the total deficit, we calculate the value of the gap by applying this ratio to projections and summing the yearly gaps over the period 2019 to 2025.

To calculate the additional revenue needed to keep the required level of capital expenditure below between 15 and 20 percent of yearly revenues, we first use the above calculated total deficit α and revenues in 2018 and 2019. We solve for the revenue in 2025 if linear growth gains an extra α, by letting $\alpha = \frac{(2025-2018)*(R_{25}-R_{18})}{2}$, knowing R_{18} already. We plug in the R_{25} usual CAGR formula and get

$$CAGR_{\ sustainable} = \left(\frac{2\alpha R}{2025-2018} - 1\right)^{2025-2018}$$

10. Estimating the share of the population that will remain offline by 2030

We project the share of population that will remain underconnected (i.e., those who will not adopt 3G or better cellular connectivity) by 2030.

The main data sources used for the analysis are:

— GSMA Intelligence (cellular connectivity data)

— eMarketer (online video viewer and social network user data)

— United Nations Population Division (population and urbanization data)

— IHS Markit (GDP projections)

— McKinsey's Cityscope database (income differences between urban and rural areas)

— Analysys Mason (revenue per GB trends)

— IDC Device Tracker (selling prices of smartphones)

— Oxford Economics (country-level income distributions)

— ITU (cheapest mobile data plans)

— A4AI (cheapest mobile data plans)

— Tariff (cheapest mobile data plans)

— Operator websites (cheapest mobile data plans)

Projections for the share of population remaining unconnected in each country are based on barrier analysis, which focuses on four main barriers to mobile internet adoption, namely availability, affordability, relevance, and readiness:

— **Availability:** To project intermediate cellular coverage by 2030, we use country-level projections from GSMA Intelligence through 2025, then extrapolate through 2030, while taking into account the projected rate of urbanization (more people moving to areas already covered by mobile networks).

— **Affordability:** To project the affordability of mobile internet use, we consider three developments: the distribution of household incomes, the price of the cheapest 4G smartphones, and the monthly cost of the cheapest entry-level mobile data subscriptions. To determine household income distribution in each country, we use Oxford Economics projections. To determine the price of the cheapest smartphones, we use the price of the cheapest 3G smartphones during the 4G lifecycle as a proxy for the pattern that 4G smartphone prices are likely to follow during the 5G lifecycle. To determine the cheapest entry-level mobile data plans, we consider two scenarios: In the first scenario, entry-level data plan prices would decrease as a result of decreasing costs per GB. In the second scenario, entry-level data plan prices would decrease in tandem with the average revenue per user in each country.

— **Relevance:** To project the relevance of content, we use two proxies: the number of online video viewers and social media users in each country. We use eMarketer projections through 2022 (online video viewers) and 2023 (social media users), then extrapolate through 2030. We take into account slowing growth rates in countries with high penetration.

— **Readiness:** To project readiness for mobile internet usage by 2030, we use two proxies: literacy and mobile phone ownership (digital literacy). For literacy, we use current and historical country-level literacy rates from UNESCO and extrapolate through 2030 using a population pyramid model that takes into account the differences in literacy rates of each age group.

To combine the results, we take the availability of coverage as the first limiting condition. We then consider the existence of other barriers and overlap between them, based on information on the current unconnected population, and then calculate unconnected population for each year between 2019–30 based on the trends described above.

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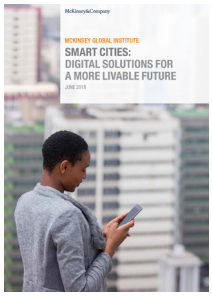

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